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State of the Art of Using Virtual Reality Technologies in Built Environment Education.

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STATE OF THE ART OF USING VIRTUAL REALITY TECHNOLOGIES IN BUILT ENVIRONMENT EDUCATION

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ABSTRACT

This paper reports on our major findings concerning the application of virtual reality technologies in built environment education (BEE). In addition to an analysis of the current trends and developments in current virtual reality technologies and systems, it also evaluates their educational usability and effectiveness in the mirror of the literature. First, a reasoning model is introduced, which is used as a structuring skeleton of the paper. The context of the analysis is learning experience of BEE students who tend to form individual perspective and expectations. When the experience and perspective of the virtual reality developer differs from that of the user the virtual environment-based learning may result in a perceived negative experience because of a strong focus on the reality of the virtual tasks. We found that the literature does not specifically address the issue of learning experience when different virtual reality technologies are used in BEE, but it does emphasize the importance of usability evaluation to enhance the effectiveness of applications. It was also found that stimulation of learners plays an important role and this explains why conventional single-person oriented (HMD-based) and multi-person oriented (CAVE-based) solutions are complemented with game-based stimulation. Future research should consider how game-based simulation can be applied in virtual reality learning environment in the context of BEE.

KEYWORDS

Usability, virtual reality, built environment education, human interaction, gamification, learning experience

1. INTRODUCTION

The objective of this paper is to review how built environment education (BEE) has benefited from the recent advances in virtual reality technology. Previous research has highlighted the influence technology is having on BEE [1]. Virtual reality (VR) is defined as 'computer generated simulation of three-dimensional (3D) images of an environment or sequence of events displayed on a screen which enables user interaction' [2]. VR is also defined as 'an experience in which a person is surrounded by a computer generated 3D representation and is able to move around in the generated virtual world and see it from different angles, reach into it, grab it, and reshape it [2].

VR systems are typically developed to serve as: (i) advanced multi-media interface, (ii) immersive three-dimensional problem solving systems, and (iii) networked collaborative work environments [3]. The range of technologies that enable their implementation extends from visual and audio technologies through tactile, haptic and limbic technologies to brain, cognitive and game technologies [4]. Though many published technical papers report on successful technology developments, system implementation and application, and positive impacts, there are still numerous open issues, many limitations and bottlenecks (e.g. in terms of real-time computation), and even disadvantages such as cyber sickness, nausea, postural instability, visual side effects, and after effects [5].

Not considering specific application needs, 'VR is generally necessitated by: (i) the growing complexity of engineering tasks, (ii) the need for optimization of

the measures of product development (time, cost, quality, impact), and (iii) the demand of optimal utilization of resources and assets (expertise, competencies, staff, high-tech equipment, software tools), and (iv) the on-going globalization and division of labour and knowledge.

VR has gone through a rapid evolution in the past three decades and has become a mature technology. But it has also gone through an intense diversification. As a result, many different technologies and implementations exist that range from entry-level desktop tools and applications to immersive portable means to high-end immersive, multi-media, computer-aided virtual environments (CAVEs) [6]. Head-mounted displays (HMD) have become the most commonly used device to provide visual interface. In large-scale industrial and academic applications CAVEs are used in which images are projected onto the walls, the ceiling and the floor using various projector technologies [7]. The immersive simulation is based on the visual degrees of vision provided to the viewer.

Among its uncountable practical applications of VR systems, educational utilization has remained somewhat limited. Desktop oriented VR uses display technologies to provide visual images on a computer screen and some other form of modalities such as sound [8]. A significant stimulation for further research and developments comes currently from the computer game industry. Recent advances in game technology have seen the research literature progress from describing how VR can benefit built environment education (BEE) to describing how actual VR applications are developed and applied [9]. The literature in the past five years highlights how the competition within the game-based computer industry has provided new and exciting VR game engine technologies [10].

The Architecture Engineering and Construction (AEC) industry has also begun to take a more keen interest in VR training applications [11]. This complex industry relies on well-established specialized disciplines tasked with completing clearly identified work flow specifications. It is as a result of intensive collaboration and communication among the various specialists the final construction project is completed to the satisfaction of all stakeholders [12]. Regardless of the VR technology used, immersive or non-immersive, the AEC users need to visualize the design and construct information in photo realistic three-dimensional

interactive images [12]. In order to be effective, VR must allow for multiple persons interacting within the environment [13].

At the beginning of the 21st century, AEC projects are more and more complex and require a larger more diverse design team. The Technical Research Centre of Finland (VTT) depicted an interesting analogy of AEC integration in construction, shown in Figure 1. The Islands of Automation reflect the independent computer applications in specific specialisms like design, construction and project management [12]. The time line is captured via the contour line. The current coastline reflects the frontier of the research and applications in 2010, while the coastline of 2000 was the goals that the researchers have set out to achieve before the next century. Advances in VR technologies combined with the efforts of both researchers and AEC practitioners imply that the water level has dropped [14], and bridges are built between the islands. Figure 1 can be seen as an imaginative description of the evolving process of integrated computer applications in construction industry.
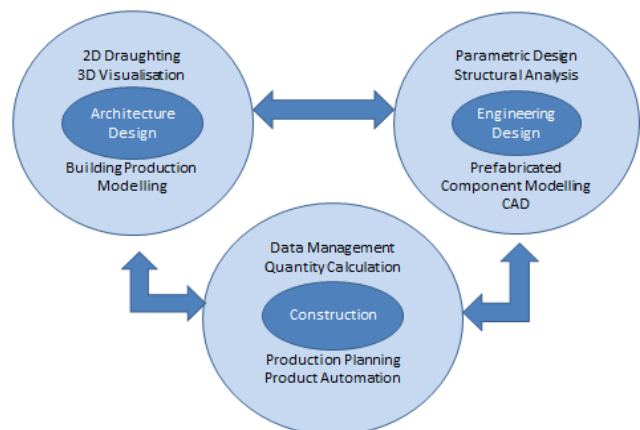
Figure 1   The Islands of Automation (adaptation of the work of VTT, Finland)

The AEC practitioners are currently using VR technology such as Building Information Modelling (BIM), which is a very minimalistic 3D and 4D integrated CAD package to construct and test design, and to walk through the virtually completed project. BEE students are using 3D graphics, head mounted visuals, sound and self-movement technologies to enhance the illusions for social and game based activities. Student familiarity of this technology has allowed BEE practitioners to mirror VR practices happening in both the social and professional real world.

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This research sets out to review the literature relating to: (i) the current state of the art of use of VR in BEE, (ii) the challenges for VR in BEE, (iii) the time and effort required developing current VR and AR environments and its efficiency as a teaching aid, (iv) the effect social game technology has on cognitive simulation for a generation, (v) the introduction of current VR and AR technologies to BEE and measuring their effects, (vi) the current applications and experiences within BEE, (vii) the consideration of human factors and diversity issues, and (viii) the open issues and future research opportunities for VR and AR within BEE.

2. REASONING MODEL

A review of how BEE has benefited from VR technology requires a systematic scientific approach. In order to structure and systematize our explorative research, we have introduced a reasoning model. This reasoning model is depicted in Figure 2. This summarizes the objectives and data sources for our research, but it was also used to structure this paper. The success of VR technology is dependent on: (i) the human user at the core, (ii) the application challenges in BEE, (iii) the sophistication of the VR and AR technologies. The level of acceptance of a VR implementation has a correlation with how the technology supports the illusion of human senses when interacting in the virtual space [12].

In addition, the cognitive simulation and gamification are co-dependent on how the technology is treated and presented. From the perspective of research, acceptability is one of the most important aspects. Due to the complexity, there are still many open issues concerning the efficiency of the current applications and the overall user experiences. In the end, acceptance is heavily influenced by how VR and AR technologies are viewed by the technology developers and the end users. Viewing these technologies as part of a suite of technologies, which when correctly utilized can comply with the objectives and enhance the results of human activities, reflects an objective position [12].
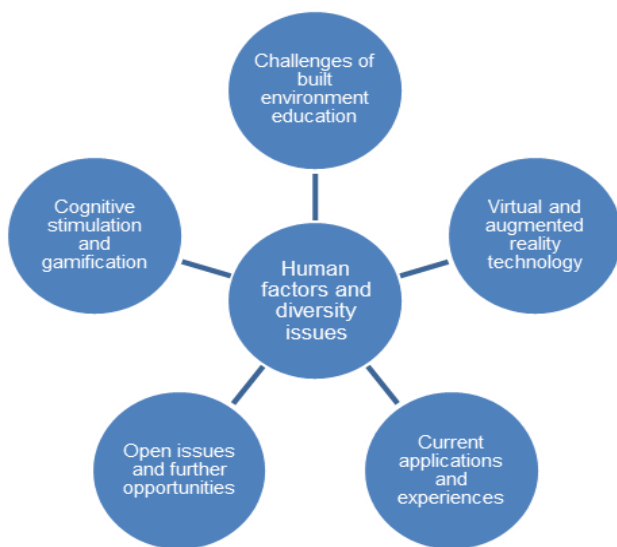
3. CHALLENGES OF BUILT ENVIRONMENT EDUCATION

The fundamental challenge for BEE is the provision of real knowledge that can be transferred and used in the real world [14]. The difficulty in the early development stages of VR and AR technology was the provision of realistic context rich scenario and the limited resources to bring the real world into a classroom setting [15]. Today's advancement in VR and AR technologies, brought about mostly by the electronic game development industry and Autodesk BIM software, has resulted in virtual construction becoming widely accepted in the AEC industry [16].

BEE has been researching the concept of using VR for a number of decades. The past few years has seen an explosion of data in the applications domain and theories concerning the human factor [9]. With high investment by industry technology is now providing very realistic models for almost every real life scenario further enhancing the benefits game engine technology brings to BEE [9]. The question of learning and how people learn best has been at the forefront of educators minds since learning and teaching began [17]. Information technology has forced educators to take another look at learning space.

When a new technology first emerges, there is usually a period of time required to firstly understand it before applying it. The application tends to be an attempt to make the technology fit familiar traditional teaching methods [17]. For example, when comparing traditional classroom based learning with distance learning using e-learning technologies the literature tends to highlight the advantages of one over the other. However, they are very different as demonstrated in Table 1 [18]. It has taken a number of years for educators to build up the required skills that allow the practical delivery of proper e-learning programmes [19].

Validation of technologies, such as computers, projectors, networks and electronic media, only

Figure 2   Reasoning model

Table 1 Main advantage and disadvantage of traditional and E-learning [19]

	Traditional learning	E-learning
Advantages	• Knowledge exchange • Skill development • Interaction between learner and teacher • Socialisation • Immediate feedback • Motivating leaner • Being familiar to both instructors and students	• Knowledge sharing • Providing any time accessibility to course materials • Adds pedagogic benefits • Cost effective for leaner • Available to global audience • Unlimited access to knowledge • Helpful for instructors
Disadvantages	• Class room size • Student teacher ratio • Accessibility • Expensive to deliver • Instructor-Centred • Time and location constrains	• Costly to produce • New skills needed • Affordability • Minimal social interaction • Lack of immediate feedback

happened when it is demonstrated to the human user how they can improve their abilities as both educator and learner [12]. Simulation is an effective and cost efficient approach to enhancing knowledge transfer, and improving performance [20]. The best example of this is in the area of flight simulators [20]. VR and AR immersive and non-immersive simulators if designed and integrated appropriately can be applied effectively in training [21]. The drawback to the current VR technology is its validity as an education tool [10].

For the moment, a relatively small minority of built environment educational professionals (human users) are using the technology. The majority are sticking with more traditional classroom-based, workplace mentoring, site tours, and apprenticeship models of learning [10]. The idea of students taking control and managing a tutorial tool far better than the teacher makes most teachers nervous and yet for some it brings exciting challenges [22]. Investment in the skills development for teachers to be able to teach in environments using different applications and user interface has not yet been fully evaluated. The result of a person's learning experience can determine improved performance and measure the potential for future learning success [22]. Established evidence-based theories of learning are now recognized as central to the development of learning practice across all fields of learning activity. Because learning is a process that leads to change it is important to be conscious of learning theories and to embed them into the design and implementation of virtual reality educational activities [22].

VR technology allows a cohort of students to collaborate and learn together in a virtual community setting [23]. As previously stated in this paper, BEE has introduced VR as a means of bringing real world practice into the classroom. Desktop oriented VR can be delivered via the internet to large numbers of students [24]. VR is an interactive technology, which provides students with the opportunity to learn by doing and lends itself to student centred, rather than teacher centred learning [25]. In relation to the experience of the students, an analysis of the learning styles of built environment (BE) students and how these are accounted for in the VR classroom has yet to be considered. This analysis is important as it can indicate the reason why one students experience differed from another [25]. How tutors, teachers and lecturers improve teaching practice will influence on going improvements in technology, but equally as the technology improves so will the teaching techniques. Laurillard, D. has pointed out that instructional designers should drive VR learning, not the technical developers [26].

Ravenscroft, A. argues that in order for VR to truly transform educational practice, the roles of the stakeholders in conjunction with the technology should be examined [27]. Engaging in an evaluation process affords the students and lecturer the opportunity to contribute to the effectiveness of the VR delivery. Teacher and students bring experience knowledge and understanding of previous education and experience with information technology. This has an influence on how the students and teachers make sense of the material presented and how they will go about studying and using it. Students and teachers will participate with an established form of study and teaching habits, which may be inappropriate for VR learning and teaching [28].

The design of VR classrooms for built environment must provide teaching and learning supports as well as peer supports as an integral and realistic part of the learning environment [29]. The result of a person's learning experience can determine improved performance and measure the potential for future learning success. When the experience and

perspective of the virtual reality user differs from that of the developer the effectiveness of the virtual environment in terms of improving learning may result in a perceived negative experience because of a strong focus on the functionality of the virtual tasks.

In conclusion, the investigation of the challenges of BEE will involve the following issues: (i) the learning styles and the experiences of students, (ii) the validity, efficiency and effectiveness of VR technology as an education tool for BEE, (iii) if the amount of investment in the VR skills development for teachers and the time required for perfecting before becoming competent to teach in VR environments is currently justified for BEE, (iv) if teaching practice needs to be considered by VR technology developers as having an influence, or as and when the technology improves so will the teaching techniques, and (v) to what extent is there a need to engage in an evaluation process with the students and lecturer to guarantee the effectiveness of the VR delivery?

4. VIRTUAL AND AUGMENTED REALITY TECHNOLOGIES

Traditionally industry relies on standard forms of information such as Gantt schedules, drawings and written specifications to communicate to all stakeholders involved in any given construction project [30]. With advances in computer graphics and computer aided drawings (CAD) the way traditional information is presented has started to change [31]. VR technology and in particular desktop oriented game-based technology complements advanced CAD technology. The recent introduction of VR into industry has now only began to be exploited as up until very recently there was very little evidence about the appropriateness of introducing 3D models for the various stages of construction projects [32]. It is the introduction of BIM and parametric CAD that has enabled VR technology and the more advanced modelling tools to become more acceptable to AEC practitioners [33].

Augmented reality (AR) is where digital information is inserted into a predominantly real world view [34]. By combining physical and virtual worlds users can manipulate how they interact with that world. The technology augments virtual information on top of the real world while continuing to provide the user with control from their perspective and their level of interactive requirements [35]. AR provides virtual objects which gives the user a real world view and

enhances the user's perception and interactions. BIM and parametric 3D CAD technology feature prominently in the creation of a basic framework for educational AR and VR environments in AEC [36]. Figure 3 illustrates a typical workflow for BIM technology to VR game engine technology. The objects are modelled using parametric CAD. The added usability advantage of using parametric CAD is that the models are designed as single primitives which can be easily configured for many uses. For example, a model depicting a block wall can also be used to depict a stone or plaster finish without the need for developing a new model each time.
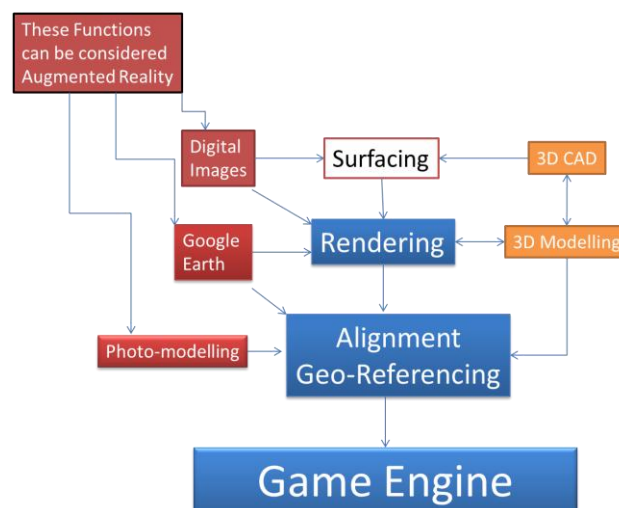
The flowchart shown in Figure 4 depicts the workflow for various software functions combing augmented reality and virtual reality for creating gaming environment. The workflow illustrates augmented reality using Google earth, photo-modelling or images of the real object and processing and aligning them with other modelling formats before importing them into game engine platforms [37].

The hardware and software technologies for AR and VR are almost the same. The virtual scenes, 3D objects and interactivity are generally equal and built using the same game engine platforms [35]. AR and VR differ in that AR tries to supplement and enhance the real world while the VR tries to replace it. Both AR and VR produce simulations of a real world environment developed through game engine or other such computer software and provide a human interface experience. The basic components for AR and VR systems are feedback displays and interaction devices. Immersive computer generated environments are created by use of stereo/3D display. Recent advances in head mounted devices is enabling desk top oriented VR and AR to become immersive.

In the period from 2005 to 2011, VR and AR technologies have moved closer towards an improved standardized framework and as a result there is a greater demand for the integration of VR with parametric CAD [38]. The literature indicates that to date no standardized integration between the real and VR has been identified and calls for further research which focuses on standardized integration [39]. The most recent studies of applying VR and AR into built environment concentrate in the main, on proof of concept, testing and feasibility.
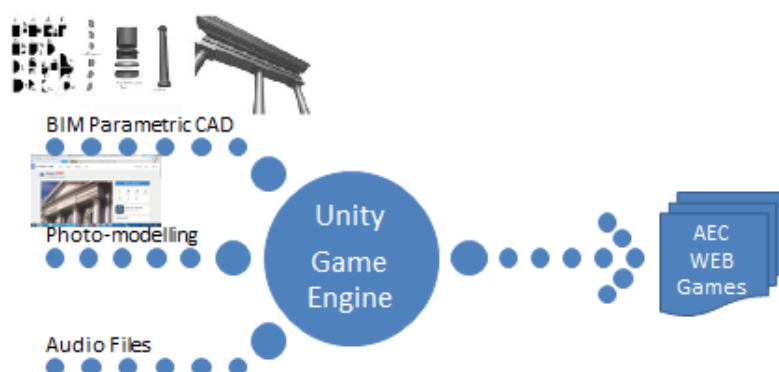
Figure 3 Workflow from BIM to Virtual Reality

Figure 4 Workflow showing software functions

(*Combing augmented reality and virtual reality for creating gaming environment*)

The necessity for these studies is justified by virtue of the fact that VR and AR systems are not adverse to failure [39]. The failure may sometimes be attributed to the technology or on other occasions is a direct result of little to no consideration towards human factors and diversity issues discussed later on in this paper. Another key factor to the success or failure of VR and AR is the developer's familiarity and the human users understanding of the scientific rationale behind VR and AR applications in built environment. Collaboration between AEC practitioners, human factor researcher's, game engine developers, educationalists, and others is needed to fully realize the potential in this area.

In summary the literature unveils: (i) how the introduction of BIM and parametric CAD has enabled more advanced modelling tools to become more acceptable as visual aids and forms of communication to AEC industry practitioners, (ii) the growing trend of combining AR into BIM technology before incorporating it into game engine technology, (iii) how AR and VR produce simulations of a real world environment and provide a human interface experience, and (iv) the need for standardized integration between the real and VR requires further research. The main focus of research to date considers the application of VR and AR into built environment as a proof of concept and

feasibility. Collaboration is needed to fully realize the potential of VR and AR technology in BEE.

5. COGNITIVE STIMULATION AND GAMIFICATION

Cognitive psychologists define learning as the study of how information is sensed, stored, elaborated and retrieved [40]. How learning takes place is subject to the viewpoint of the learners and their learning style. Learning styles include, but are not limited to learning through (i) reading, (ii) memorizing, (iii) thinking, (iv) writing, (v) note-taking in lectures, (vi) observing, (vii) listening to and talking with others and (viii) learning by doing [41]. The result of a person's learning experience can determine improved performance and measure the potential for future learning success.

Established evidence-based theories of learning are now recognized as central to the development of learning practice across all fields of learning activity [41]. Because learning is a process that leads to change it is important to be conscious of learning theories and to embed them into the design and implementation of VR simulated learning activities. Teaching methods developed under the assumption that students formulate ideas independent of the situation in which they are learned, fail to understand the impact of cognitive stimulation (CS) [42].

CS aims at providing stimulus, which initiates an activation of a cognitive processor response in the brain. BEE students and AEC practitioners are learning through their everyday activities. This knowledge gain is a direct result of the fact that AEC project completion is very much dependent on both the physical and the social sharing of problem solving activities. The sort of problem solving carried out simultaneously within the AEC environment is very distinct from processing of ideas solely inside one's head. Scribner records how complex mathematical calculations can be solved by practitioners using their environment directly [42].

Gamification of education happens for two reasons: (i) presentation of educational content, and (ii) facilitation and delivery of educational process. The accepted definition for gamification is applying game like operations to existing content. This manifests itself in the addition of a scoring system, varied levels of difficulties, leader boards and points to make the content interactive and improve user experience. Video games and virtual worlds excel at engagement [43].

Game engine technology can be used to store and make information available and to contribute to a student's self-construction of knowledge [44]. Simulation has proven effective in procedural skills education [45]. VR environments, are not intended to replace onsite training or classroom training, VR visualization provides an invaluable bridge between the two. Providing trainees a chance to work with the components in a virtual game world stimulates the cognitive skills. The simulation of procedural tasks gives the learner a chance to develop and refine their skills through repetitive practice in a learner-centred environment [46].

The application of VR has the potential to enhance the teaching of built environment students if correct pedagogy and learning theories are identified and applied. Gamification for the purpose of learning has been gaining momentum since the beginning of 2000 [47]. It is as a result of military investment that industry and education have had an opportunity to realize the potential of VR learning using game engine platforms. Table 2 illustrates the number of areas currently utilizing and benefiting from serious game training. Sawyer, B. and Smith, P. formulated this taxonomy table based on two axes, namely audience and purpose. Audiences include education and industry while purpose varies from advertising to work [48].

Based on the findings revealed in this section of the literature study, we can conclude that:

- Gamification of BEE activities can be based on shared domain-specific philosophy according to the needs of the learner.

- Procedural information can be continuously updated by integration of content and game engine technology.

- The application of game engine technology to BEE is a research domain in the area of cognition, involving self-awareness, perception-guided mental modelling and selective knowledge extraction [48].

- Video games and virtual worlds excel at engagement, and working with the components in a virtual game world stimulates cognitive skills.

The overarching evidence indicates that both the AEC education and industry sectors are experimenting with a wide range of computer supported technology. There is evidence on the effects advanced computer systems are having on both the education sector and the practicing or industry sector. Initial surface findings have concluded that research into what are the optimal computer support systems for BEE is lacking and warrants some focused investigation.

6. CURRENT APPLICATIONS AND EXPERIENCES

The literature to date which relates to the use of VR game-based technology to enhance BEE does not specifically address the issue of learning experience. There are a high number of cases where different virtual reality technologies are used in BEE, but they lack an emphasis on the importance of usability evaluation [9]. For example, the research of Juang, J.R., set out to use Blender, because it has been rapidly evolving to reduce the effort required by developers to build real world simulated activities [50]. The researcher divided the process of developing a construction simulation into three main steps: (i) 3D model construction, (ii) set up of physical properties, and (iii) creation of interactive logic. Using Blender, Juang, J.R. created a forklift simulation and carefully considered the advantages of producing computer simulated construction interactivity. The outcome of this research revealed the 'potential of physics-based simulation and the possibility of operating realistic virtual machines in the virtual world'. The paper documented how the Blender game engine technology provides developers ease of development, dramatically reduced development time, quality of images, stability and real time accuracy. The negative aspects considered related to clashes between solid objects. Nevertheless, the paper does not consider how these simulated environments can enhance the expertise of a construction professional and provide for a more effective form of knowledge transfer in BEE.

The research work of El Nimr, A.A. and Mohamed, Y. investigates 'simulation modelling as an effective approach for analysing construction operations' [51]. Construction professionals use visualization in design, planning, implementation and delivery of construction projects to communicate the project deliverables. The research analyses the use of video game technologies in the development of construction project simulated visualization. It considered how 2 different game engines (Blender and True Vision) could be used to develop independent 3D models and export them into

Table 2 The taxonomy of serious games (originally published in [48] as work in progress)

	Games for Health	Advergames	Games for Training	Games for Education	Games for Science and Research	Production	Games as Work
Government & NGO	Public Health Education & Mass Casualty Response	Political Games	Employee Training	Inform Public	Data Collection / Planning	Strategic & Policy Planning	Public Diplomacy, Opinion Research
Defense	Rehabilitation & Wellness	Recruitment & Propaganda	Soldier/Support Training	School House Education	Wargames / planning	War planning & weapons research	Command & Control
Healthcare	Cybertherapy / Exergaming	Public Health Policy & Social Awareness Campaigns	Training Games for Health Professionals	Games for Patient Education and Disease Management	Visualization & Epidemiology	Biotech manufacturing & design	Public Health Response Planning & Logistics
Marketing & Communications	Advertising Treatment	Advertising, marketing with games, product placement	Product Use	Product Information	Opinion Research	Machinima	Opinion Research
Education	Inform about diseases/risks	Social Issue Games	Train teachers / Train workforce skills	Learning	Computer Science & Recruitment	P2P Learning Constructivism Documentary?	Teaching Distance Learning
Corporate	Employee Health Information & Wellness	Customer Education & Awareness	Employee Training	Continuing Education & Certification	Advertising / visualization	Strategic Planning	Command & Control
Industry	Occupational Safety	Sales & Recruitment	Employee Training	Workforce Education	Process Optimization Simulation	Nano/Bio-tech Design	Command & Control

one common visual simulated environment. This research proved that game engine software is evolving rapidly to allow novice programmers to develop realistic virtual simulation easily with minimum man hours and cost. This research does not consider how these advances can enhance cognitive simulated procedural learning in BEE.

Fairuz, M. investigated the need for 3D visualization of designs [52]. The research concentrated on how the Torque game engine could enhance the design review process. By eliminating the need to use traditional 2D detailed multiple architectural drawings layout in an open plan site office. It provided detailed information on how assets were developed imported into a virtual environment and easily manipulated to resolve potential real world conflict and clashes. The work of Fariuz, M. also unveiled that within the Torque game engine is a built-in capability to reproduce code thereby repeating tedious cumbersome work. The research focused on how game engine technology will reduce potential real world conflict thereby reducing build delay time and increasing construction productivity. The usability from a BEE stand point was not considered.

Lin, K.-Y. carried out research into education for the purpose of promoting a safe and healthful working environment in construction [53]. The research proposed a Safety Inspector computer game. The game prototype was developed to test issues such as real world simulation, student self-learning, student engagement and interactivity. The chosen game engine package was Torque 3D. The prototype game was tested with the involvement of students, the student's interaction such as engagement, increase of learning interest, interactivity and engagement were measured with learning process and overall motivation. The concluding findings revealed more questions about how simulated construction environments enhance the expertise and the learning experience of the players. The pilot test among 5 students demonstrated that the visually realistic virtual environment can be replicated but the sensory and interactivity virtual environment has not yet been perfected. This research has gone someway in measuring the learning experience and motivation of a small group of construction management students. It acknowledged the need for further research into the how much added value does virtual simulated learning provide.

The research of Han, S.W. considers managing the combined impact of variability and interdependency on construction performance [54]. His analysis of a game termed the 'Parade Game' concludes that virtual reality experience does not mirror real world experience. Construction in today's real world tends to be large scale and more complex projects. Han contends that because of the sheer size and complexity of most large scale construction projects 'small variation can result in tremendous ramifications on overall project performance'. Accordingly, Han, S.W. argues that simulated virtual environments provide an affective learning tool when utilized in conjunction with traditional classroom-based learning but 'are not fully capable of demonstrating complexities, dynamics and uncertainties of construction projects'. The conclusion of this research is that a vital part of simulated learning is face to face interaction if the pedagogical value of the game is to be maximized.

As a conclusion, the provision of realistic context rich VR technology has never been more plentiful. The literature is rich with examples of how game engine technology affords the novice user with the opportunity to build virtual construction scenarios. What is not yet researched is how effective this rich VR technology is for enhancement of expertise in comparison to the existing tried and tested traditionally modes of delivery.

These case studies provide anecdotal evidence that:

- The issue of developing and profiting from BEE learning experience has not specifically addressed in research to date.

- The current game engine software is evolving rapidly to allow novice programmers to develop realistic virtual simulation easily with minimum man hours and cost

- There is a need for further research into the how much added value does virtual simulated learning provide in the case of BEE.

7. HUMAN FACTORS AND DIVERSITY ISSUES

The influences human-computer interactions (HCI) can have on the effectiveness of virtual reality delivery in BEE is still under researched. There is a need to evaluate the efficiency and effectiveness of virtual simulated learning compared to traditional methods. Shneiderman, B. states that well designed

HCI must provide informative feedback, permit easy reversal of actions, support an internal locus of control, reduce working memory load, and provide alternative interfaces for novice and expert users [55]. When an interface is well designed humans are highly tuned towards images and graphics [56]. How these images detract from the learner's ability to concentrate on procedural or cognitive learning requires a more in depth study.

As outlined earlier in this paper validation only happens when the technology demonstrates to the human user how it can improve their abilities. Usability is determined by how well a user can learn and use the technology to achieve their goals and how satisfied they are with the process. Human diversity is a central consideration which must be applied to all forms of education and must be accounted for when developing teaching tools. VR and AR technology tools are not yet common place in BEE in favour of presentation using visual aids such as smart board and projector technology. The challenge is to investigate how we can provide a user, without disproportional effort, acceptable platform which enables effective communication of knowledge.

Socialist cognitive development theories state that cognitive growth is fostered when individuals encounter experiences and demands that they cannot completely understand or meet [57][58]. As a result, the student must work to comprehend and master the new or unfamiliar. Ruble, D., a developmental psychologist, works on the theory that cognitive growth and developmental changes are stimulated by events that put individuals into new situations involving uncertainty and requiring new knowledge [59]. Developing out of this theory is the need for research to discover how using AR and VR technology will contribute to the student's cognitive growth and new knowledge more effectively.

The fact that students must master the technology in conjunction with learning the new knowledge is an ideal (with the correct HCI design) incubator to foster cognitive growth in its provision of experiences and demands that cannot be completely understood or met easily. In conclusion, we may state the following propositions:

- The evidence has determined that usability is measured by how well a user can learn and use the technology to achieve their goals and how satisfied they are with the process.

- The purposefulness and convenience of human-computer interactions strongly influence the effectiveness of virtual reality delivery in BEE.

- There is a need to evaluate the efficiency and effectiveness of virtual simulated learning with in BEE applications.

- Future research will need to discover how using AR and VR technology contribute to the student's cognitive growth more effectively.

- Computer supported technology is supposed not only to support learning new knowledge about the specific subject, but also to foster cognitive development in an effective way.

8. OPEN ISSUES AND FURTHER OPPORTUNITIES

Computer technology is now at a high level of interactivity, promoted both through social and work based virtual encounters. One assumed advantage of learning in an interactive simulated virtual environment is the potential it has to expose participants to a high risk process, maintaining visual simulation and eliminating personal risk. Learning in BEE tends to conform to the learning theory of behaviourism. The development of advanced visualization and virtual environments can enhance traditional training methods and learner experience. On the other hand, according to Watson, D., we are not addressing specifically the issue of learning experience when different virtual reality technologies are used [60].

The VR and AR teaching tools for BEE need to be designed with a learner centred approach that integrates the cognitive, affective and social cultural domains. The use of these tools needs to be monitored and measured to ascertain if when used in the correct context, they can enhance educational performance of the students [61]. The rapid advancement of technology provides an opportunity to investigate and confirm the fundamental principles of Game Based Technology (GBT) in virtual simulated learning. The effect of how expertise enhancement truly benefits from the advances of GBT can only be measured when the value added theoretical underpinnings of learning in GBT are identified. The knowledge base of learning through GBT cannot be expanded with continued descriptions of how the technology has been applied to different aspects of virtual simulated learning.

The majority of BEE literature on the application of VR and AR technology is practice-based and is typically presented in a practice-based research format. Within BEE there appears to be a heavy concentration on the technology and its uses and little on the value added theory of GBT. The theoretical underpinnings of GBT in BEE require exploration and debate to provide a wider platform and a common philosophy. The literature review has highlighted:

Technology

- The need for more proof to determine if the principle of virtual simulation through serious game technology is indeed a means of education as opposed to a mode of learning.

- The need for further research in areas such as the early design part of simulated learning in virtual environments in which pedagogical supports play an important part.

- The need to investigate design principles that will

> Lessen the complication for application

> Reduce design time constraints

> Develop VR environments for the average teaching practitioner.

- The issues of learning experience when different virtual reality technologies are used in BEE teaching practice.

Pedagogy

The human factor issues requiring further research are:

- Human expectation to instantly recognize the environment and the interactive objects.

- Real time reaction and information supply.

- Accuracy, quality and detail of media and reproduction.

- The effectiveness in the VR technology in the transfer of knowledge.

The challenge for AEC teachers, practitioners and computer engineers specializing in game development is the provision of a platform which enables effective communication of knowledge and reduces the barrier to entry for most research developers. Further exploration is required to develop new design principles that will lessen the complication and time constraints for the average research game developer.

9. CONCLUSIONS AND FOLLOW-UP EMPIRICAL RESEARCH

This paper highlights how the rapid growth of VR technology in recent times has made the technology more cost effective and available to a greater majority. The reasoning model has placed human factors and diversity issues at the core of the investigation. The need to use VR and AR technology in BEE has already begun to impact on BEE and the AEC industry. The evidence reveals how BEE practitioners have started to take notice of these growing phenomena and are striving to embrace the technology for the purpose of improving the learning experience and meeting with AEC industry expectations.

The review of the literature has identified a scientific knowledge gap and consideration of this can provide focus for future research. The emerging questions not yet fully investigated and answered are:

- How should pedagogical theories and supports be combined with simulated learning in virtual environments in order to improve the expertise of AEC students?

- How can simulated learning in virtual environments be integrated into daily BEE teaching practice effectively and without disproportional effort?

The questions relating sensory interfaces, measures of effectiveness, importance of the sensation of presence, and cyber sickness are already subject to on-going investigations across many disciplines outside of the AEC industry. There is a need to consider how VR simulated learning can contribute to the holistic ecology of education and the short to

It needs to also be considered what the purpose for what students and teaching practitioners want and can use it for and how VR simulated learning shapes the learning of students.

It is the intention of the authors to conduct research into how disconnected AEC students can develop procedural competencies using VR technology and measure the objective and quality compared to co-located AEC students. The first step is to build a fit for purpose VR prototype practical classroom laboratory and to investigate what are the required pedagogical theories and supports needed. The

prototype VR environment will mirror the traditional laboratory normal used by co-located students. Figure 5 shows some results of current leading-edge research in virtual reality-based interactive experience laboratories, which intend to eliminate the identified knowledge gap.

The purpose of this VR environment is to test how simulated learning in virtual environments can be integrated into daily BEE teaching practice effectively and without disproportional effort. This future research will consider if: (i) the principles of social science, (ii) simulated learning, and (iii) cognitive science are the foundations required to develop effective enhancement of knowledge expertise when using virtually simulated learning environments. The prototype will also be used to test HCI design principles to ensure easy usability and less opportunity for distractions from the required learning.

Figure 5 Screenshot from virtual classroom laboratory Refrigeration Engineering

(created using game engine software platform)

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