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Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems

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Abstract: A web-based 3D game project was presented in this paper to demonstrate the process of using building information modeling (BIM) to create an interactive 3D on-line 'Green' training environment. The system architecture, the implementation process and major components of this virtual training environment were discussed. Existing studies on BIM-based collaborations mainly focused on local-file-sharing approach using proprietary applications. Limited research focused on using BIM as an online gaming platform to create a web browser-based interactive 3D virtual environment for collaboration, learning and/or training. The gap was partially caused by the lack of understanding how to implement a BIM-based game in web browser environment. In this paper, the authors provided an implementation example using a hospital BIM model to create an interactive web-based 3D BIM game environment to allow users to visualize and interact with the BIM components using regular web browsers. The intention of this project is to create a proprietary-independent training environment to conduct energy re-commissioning trainings for hospital facility management staff. This virtual BIM environment can potentially be customized for engineering student learning and project collaborations as well. The conclusion was that current BIM and game technology are mature enough to allow us to create serious web-based interactive learning/training virtual environment. The successful integration of BIM and web browsers paved the way for many learning and training applications, which need built-environment as context.

Key words: BIM; 3D, web-based, interactive, virtual, training, hospital, HVAC, implementation, energy retrofitting

INTRODUCTION

This research is part of a US Department of Energy sponsored veteran energy retrofitting training project, which aims to develop online training curriculum of energy retrofitting of hospital and/or commercial buildings for veterans to work as 'Green' building professionals. One of the challenges in developing this online training curriculum is how to conduct necessary on-site trainings to demonstrate the basic working principles of different complex HVAC systems, under constraints of limited training time and budget.

To answer the challenge the PIs investigated the potentials of using three-dimensional (3D) virtual site visit to substitute for actual site visits. BIM models of HVAC systems were used in regular web browsers to create a 3D game environment for virtual site visit. This primary objective of this research is to develop a web-based 3D virtual HVAC 'on-site' training environment to provide realistic 3D learning context of actual building and HVAC systems. The 3D BIM models HVAC systems used in this paper were created based on an actual VA hospital.

Since the targeted users are often located in geologically dispersed locations across the globe, and they may not be able to access the learning materials at the same time, web-

based virtual self-learning appears to be a feasible choice. In addition, web-based applications are less likely to have issues with hardware devices and issues with updating contents compared to standalone game applications.

Web-based 3D interactive game environments have been used in many areas including science, engineering and medical training (Cook et al. 2011; EI Rhalibi 2009 et al.; Hendaoui et al. 2008). Its value in learning and training was widely recognized (Cook et al. 2011; Gonzalez 2008). Their application in architecture, engineering and construction (AEC) area have gained increased attentions from both industry and academia alike (Kumar et al. 2011; Guo et al. 2011; Lin et al. 2011), particularly due to the increased presence of 3D design technology, such as building information modeling (BIM) (Eastman et al. 2011; Shen and Issa 2010) and/or Google SketchUp (Choo & Phan 2010) in design, construction and research communities.

A major challenge in creating a realistic built environment in 3D game engine is to created large-scale, detailed, and realistic building models. Two technical issues were responsible for the difficulty: 1) most 3D game engine is not designed for creating complex detailed building designs. So it is difficult and time consuming, if possible, to create realistic building models using game engines' own design functions. 2) Data interoperability between design software and game engine was a significant issue previously (Shen et al. 2007). Few game engines were able to import 3D design files seamlessly into the web-based game environment while maintaining the desired detailed information about building properties.

Recent progress in data interoperability in AEC modeling software as well as the new development in Web3D technology has created opportunities to use existing 3D design, especially BIM models, to create complex realistic built environment for immersive learning or virtual 'on-site' training.

In this paper the authors presented an implemented case to demonstrate the feasibility and potential of creating web-based interactive 3D virtual built environment using BIM models. The models included a hospital's floor layout and the corresponding HVAC systems. The intended training topics included how to fix and enhance the performance of hospitals' HAVC systems. Two important advantages of the virtual 'on-site' training environment are 1) it allows trainees to access, observe, and manipulate the different types of hospital HVAC systems without affecting the actual hospitals operations; and 2) trainees do not need to travel to the actual hospitals sites to see how the actual HVAC systems works. Three specific objectives were considered in this project.

1. Identify appropriate architecture, procedures, components, platforms, and data for creating the web-based on-site virtual training environment.
2. Identify appropriate game engine, which is able to take necessary BIM information in the game environment.
3. Develop virtual 3D immersive training scenarios and visualization of the HVAC systems. Users are expected to be able to observe realistic animations of airflows of supply, return and exhausting in normal and abnormal conditions.

RELATED WORKS

Web-based immersive learning environment (Floryan and Woolf 2011; Cai et al. 2008) has gained increased attention in recent years due to the significant advancement in information technology and cyber-infrastructure. For example, Simpson et al. (2007) have developed two cyber-infrastructure-based repositories to support engineering design among three universities; and Moon et al. (2008) have developed a cyber-learning system to support

aerospace engineering. Study (Dede 2009) indicated that immersion in a 3D interactive environment can contribute to effective learning by allowing multiple perspectives, situated learning, and transfer.

2nd Life as a major player in 3D virtual game environment gained significant interests from educational community due to its potential of creating an immersive virtual learning environment (Mallan et al. 2010; Warburton 2009). However, one of its major drawbacks is the difficulty to create realistic built environments using its own primitive-shape library, and it has significant issues in its interoperability with BIM models (Ku 2011). Due to this limitation, its applications in ACE community were limited.

BIM models are able to provide realistic and detailed 3-D virtual environments with graphical and non-graphical data that represent key properties of building system. BIM has gained significant market in AEC industry in recent years. Its applications originally focus mainly on design and construction (Eastman et al. 2011; Zhang and Hu 2011, Shen and Issa 2010). More recently, the applications started to extend into buildings' lifecycle management (Wang and Shen 2011), such as as-built documentation (Tang et al. 2010) and facility management (Vanlande et al. 2008).

Despite the rapid development in BIM's applications, using BIM model to create 3D interactive computer game is still relatively new. Existing BIM-based computer game research were mostly focused on stand-alone game application. Kumar et al. (2011) developed BIM-Unity3D based game application for evaluating healthcare facility designs. Lin et al. (2011) developed a single-player game for construction safety training. These two projects were not web-based, which means that a standalone game application is required to be installed on user's computer.

Few projects and literature on web browser-based 3D interactive BIM game environment are found to the authors' best knowledge through extensive literature reviews. However, since web browsers are standard components of almost any PCs and mobile devices, developing web-based 3D interactive game environment will has significant value and can provide general public broader accesses to, and sharing of, virtual learning environment.

THIS PROJECT

The selection of game engine

Game engine selection is the key in achieving the goal and objectives set for this project. Several criteria were set for candidate game engines considering the open accessible nature of the developed application. The criteria included capacities of 3D, cross platform, supporting importing BIM exporting file format (especially FBX file format), supporting different operating systems, open source, and affordability. After extended screening process, Unity3D game engine (Unity3D 2011) was identified as the game engine used to carry out the tasks. Unity3D can take BIM models through FBX file format to import geometric, and texture, and other material properties from Autodesk Revit BIM models. And the developed games can be deployed in Windows, Mac, and iOS and Android systems.

The framework of the system

Figure 1 shows the architecture of the proposed system. On the server side, we deploy the source files including 3D model data and offline game deployments to support the Web platform interface. On the client side, the proposed the 3D interactive environment can be acceptable by multi-type browsers via a Web player plug-in. The interactions and object behaviors in user-model are defined using the scripting language functions embedded in both

webpage HTML files and 3D game deployment. In game development, the objects were imported in 3D environment as "asset" from BIM models through FBX file format.

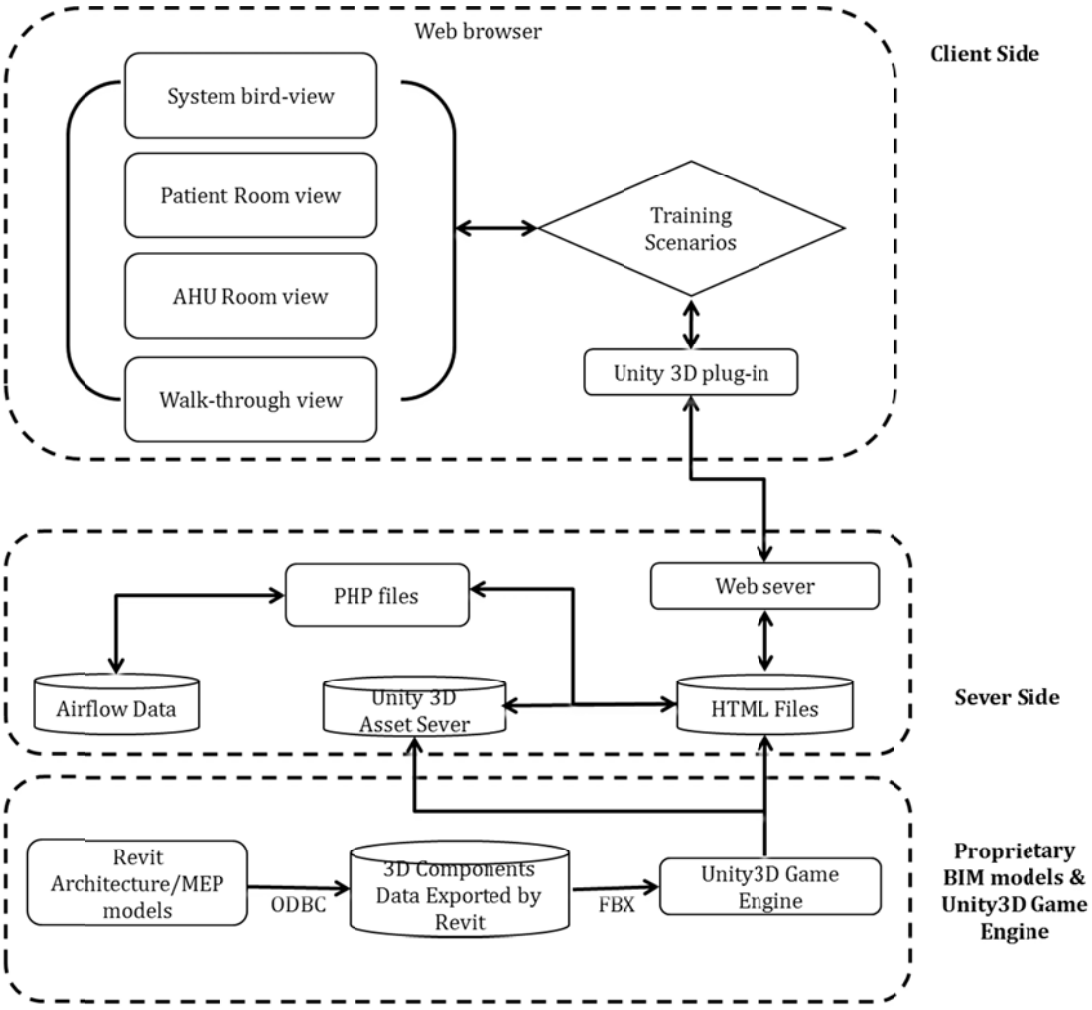

Figure 1.The architecture of the implemented game environment

Other than entertainment purpose, games developed for education, training, research exploration purposes are often called "serious game". So one notable component in this developed serious game is the airflow database, which was the actual HVAC data measured from the on-site inspections. The data was pulled out when users click the corresponding objects while playing the game. The data was also used to control the effects of the particle simulations, which animate the airflows of fresh air, return air, and exhaust air in the HVAC systems.

Figure 2 below illustrates the web-based interaction design using three-layer of abstractions: user interface exported by game engine, middle layer functions in HTML files and backend databases. Such three-level framework enabled each simulation in the frontend connected to the database through script functions in HTML files. Web based programing provides solutions for database access control and also guarantees the security of the database, and reusability of the scripts. Due to the reusability of the script functions, new scenarios in hospital operation or a brand new training environment can be easily loaded on the same database side without substantial amendments.

When a user activates a scenario in Figure 1, the user interface will make a function call (JavaScript functions) to HTML file on client side. In the HTML file, JavaScript and PHP functions transfer variable values to each other. On the server side, PHP files will select corresponding data from database and return them to the target functions in HTML file. As a result, the user would see the corresponding data on the webpage.

In this developed prototype, multi-player functions were not implemented. Future work can extend multiplayer functions into the same simulation environment.

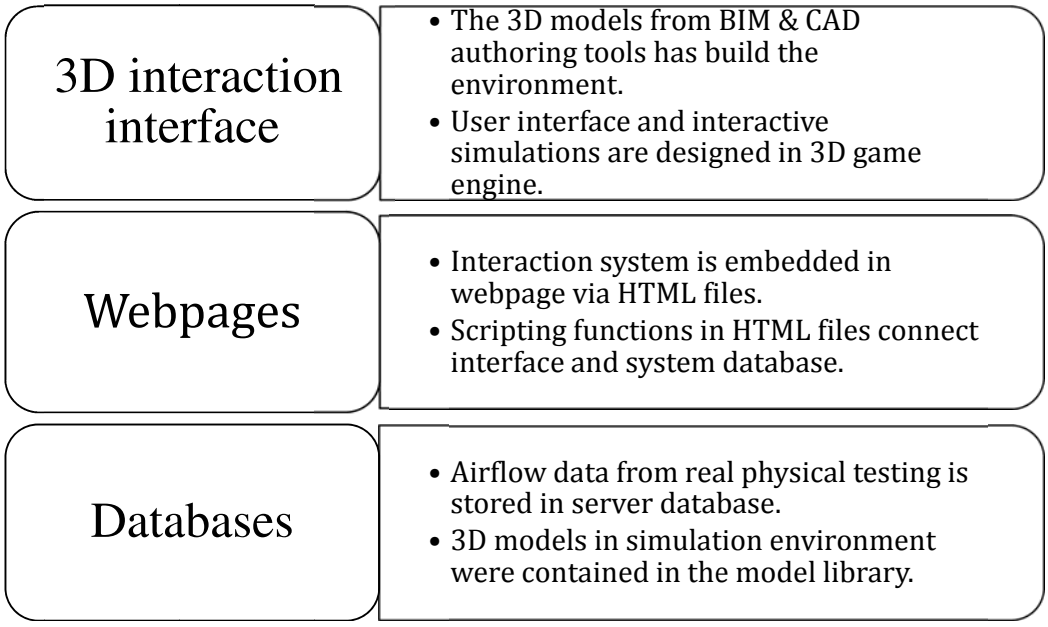

Figure 2 the web-based three-layer interaction design

The use of multiple-camera views to control training contents

In games for entertaining purpose, unpredictable encounters and surprises were often used to attract players' attention. In the proposed system, the authors felt the need of reducing surprises and unpredictable user behaviors in order to make players focus on the training scenarios. To achieve this goal the authors designed a series of controlled camera views to represent training scenarios. Game players will have particular position view to watch the specified events/scenarios by clicking the different location buttons. This design effectively eliminated times wasted on navigating through buildings to find interested locations in the building. In serious games we believe this is a good way to control the training contents intended to deliver to the players. Figure 3 illustrated the specified camera views labeled in Figure 1.

For example, cameras in 3b, 3c and 3d, were set with constrained views, which can only be used to look around in that particular room. In this way unnecessary walk-through and/or unintentional moves will be banned to let player just focus on the different flow patterns.

Position fixed camera views can also be used to help players to navigate through complex buildings. Figure 3d showed a walk-through scenario in a complex building using orthographic camera view as a navigation map provided in Unity3D. The map was overlaid on top of the 3D walk-through view on the lower-right corner. The red arrow on the map showed the player's actual location and facing direction.

So far, to the best of our knowledge, we have not seen literature on discussing the use camera control to help game players to focus on the intended contents. Further research might be needed in this area.

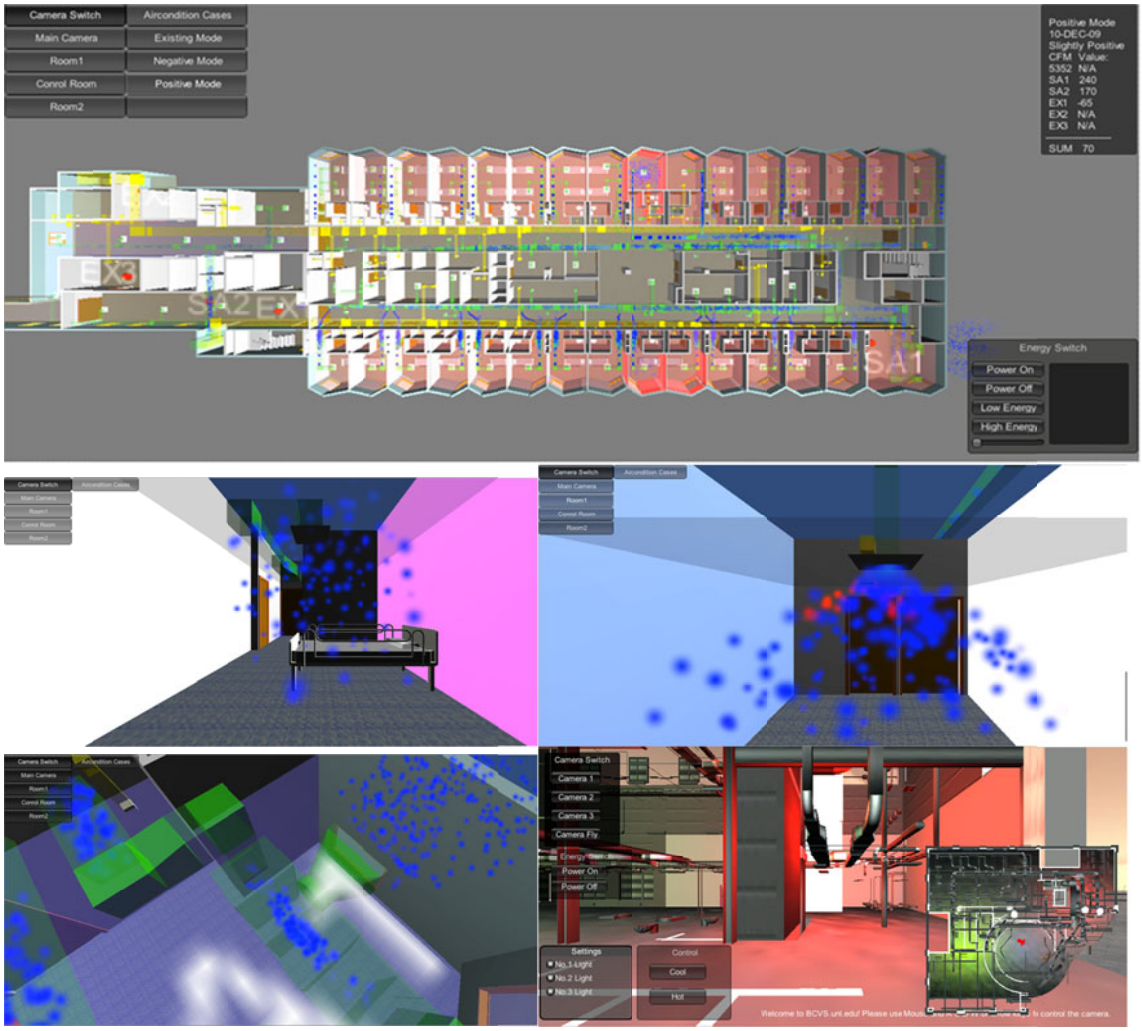

Figure 3. The use of camera views to direct players to the intended learning contents 3a (top)-floor view; 3b (middle)-patient rooms; 3c (lower-left) AHU room; 3d (lower-right)-walk through view with a navigation map

Correlate particle effects with airflow data

In this project, the actual airflow data was taken from six sampling points in the HVAC system at different building locations, which were labeled on the floor views of Fig 3a. Particle effects were used to animate the airflow patterns, which is normally invisible when visiting actual building systems.

Unity 3D provide a well performance particle system which are primarily used for effects such as smoke, fire, water droplets, or leaves. In HVAC system, we design the shape of it to be airflow objects in supply and exhaust duct. To distinguish two parts, we set the

supply airflow blue color and red color for exhaust. In different scenario simulations, the energy and emission of the particle system will be also related to the value from airflow database.

The materials and render of the hospital building are also very important. For easy monitoring, a transparent ductwork and ceiling group are needed. We set the alpha value of the objects color to be under 0.35. From the patient Isolation room in Fig 3b and AHU room in Fig 3c. We can see that the airflow going through the duct and spreading in isolation room is well simulated by the particle system.

In order to make the animated airflow match the field-measured data, a pseudo correlation was used to correlate particle densities to the actual airflow values. This correlation was purely for illustration purpose, and did not have any computational fluid dynamics (CFD) bases. However, actual CFD simulations could be added as video clips in this game environment in future development.

Example training scenarios using this 3D game environment

One training case is to show game players the status of room pressures, which are critical for some special rooms in hospital. For example, patient insolation rooms need to keep certain level of negative pressure in order to prevent spread out of contagious airborne germs or particles. Different color codes were assigned to areas showing positive, negative, and neutral air-pressures, so users can watch how room pressure changed based on the sampled measurements. For example, Table 1 showed significant level of negative pressure (in-balanced) at Day 1, and the situation was addressed by increasing fan frequency at SA1, and decreasing fan frequency at EX1. The result of the changes is a balanced negative pressure at Day 2.

Table 1. Example data sets used in creating training scenarios

Sampling points	Parameters	Day 1 data	Day 2 data	Unit
SA1	Ward supply air	4536	5760	CFM
SA2	Lobby supply air	2141	2147	CFM
EX1	South exhaust air	-3297	-2527	CFM
EX2	North exhaust air	-4512	-4579	CFM
EX3	Lobby exhaust air	-1256	-1289	CFM
Total		-2388	-488	CFM

Note: CFM represents cubic foot per minute (CFM), which is used to measure the rate of air exchange.

In other cases, instructors can create scenarios with single or multiple faulty symptoms that are visible to the users in the 3D model, and then challenge the users by asking them to come up with corrective action. This type of problem-based case study can be very powerful when combined with 3D virtual model, which simulating the actual on-site scenarios.

RESULTS

By selecting the appropriate game engine and BIM authoring tools, we were able to create a web-based immersive 3D BIM learning environment for HVAC system on-site training. The smooth transition from BIM models to 3D game models in this project suggested that the previous interoperability issue between BIM and game applications has been improved significantly. Moreover, we found a way to add a knowledge-based module (the air-flow database) to the game environment so the virtual game environment can be used

to conduct topic-specific HVAC trainings. The successful implementation of the external-database module paved the way for more topic-specific trainings in same BIM environment. The implemented prototype provided a proof of concept of using BIM for creating serious 3D virtual game environment, which have great potentials in AEC industry. Since we have not started the testing phase of the project, results from user side are not included in this paper.

CONCLUSIONS AND FUTURE RESAERCH

In this paper, we presented the goal/objectives, the research procedure, and the findings as the result of the implementations, of a research project using BIM models to create a web-based 3D virtual training platform to provide a capacity of virtual on-site visiting to actual HVAC systems. The intended users can manipulate and interact with virtual 3D HAVC systems in the realistic built-environment context. The authors anticipate improved learning outcomes of commercial HAVC systems compared to static learning environment, in which texts, numbers, and pictures are the only learning media.

The experimented 3-D Web technology offered a potential alternate solution to conducting large-scale Green building training using existing information technology, especially 3D graphical technology, and cyber infrastructure. The success of the project can potentially lead to significant improvement in training and learning of Green technology and knowledge in engineering area.

The preliminary findings and results of this project suggested that previous barriers of interoperability among different data structures have been reduced significantly. In the case of this project, we are able to import a significant portion of data in BIM models into the Unity3D game engine. The improvement in the data interoperability may soon to unleash the potentials to create serious realistic 3D virtual environment using BIM models for numerous applications included, not limited to, learning and training.

In our case, the developed virtual 'on-site' platform is able to provide almost unlimited 'on-site' training resources, which cannot be achieved using physical resources. Another advantage of this virtual platform is its ability allowing trainees to mess-up things, which is very unlikely in a physical built facility. Since the implemented system is based on thin-client web browser, high-power desktop or workstation is not necessary to have a satisfactory performance. The implemented thin-client feature allows average laptops to have decent performance when playing with the game.

The authors would like to point out that the research project described in this paper is a proof-of-concept in nature, despite the positive implementation results. Further, and larger scale implementation of BIM based 3D virtual game environment projects are needed to understand the scalability issue of this implementation framework. Another limitation of this research is the lack of quantitative evaluations of its effectiveness from users' perspectives. Future extension of the research will address the limitations.

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REFERENCES

Cook, N. F., McAloon, T., O'Neill, P., and Beggs, R. (2011). "Impact of a web based interactive simulation game on nursing students' experience and performance in life support training — A pilot study." *Nurse Education*

Choo, SY., and Phan, VT. (2010) "A Combination of Augmented Reality and Google Earth′s facilities for urban planning in idea stage. *International Journal of Computer Applications* , 4(3):26–34, July

Dede, C. (2009). "Immersive Interfaces for Engagement and Learning". *Science*, 323 (5910), 66-69.

El Rhalibi, A., Merabti, M., Carter, C., Dennett, C., Cooper, S., Ariff Sabri, M. (2009). 3D java web-based games development and deployment. The International Conference on Multimedia Computing and Systems-ICMCS '09, 553-559.

Floryan, M., & Woolf, B. (2011). Rashi game:Towards an effective educational 3D gaming experience. 2011 11th IEEE International Conference on Advanced Learning Technologies (ICALT), 436-437.

González C and Blanco F. 2008. Integrating an educational 3D game in moodle. Simul Gaming 39(3):399.

Hendaoui, A., Limayem, M., & Thompson, C. W. (2008). "3D social virtual worlds: Research issues and challenges." *IEEE Internet Computing,* 12(1), 88-92.

Cai, H., Sun, B., Farh, P., & Ye, M. (2008). Virtual learning services over 3D internet: Patterns and case studies. Services Computing, 2008. SCC '08. IEEE International Conference on, , 2 213-219.

Ku, K.; Mahabaleshwarkar, P. (2011). Building interactive modeling for construction education in virtual worlds, Journal of Information Technology in Construction (ITcon), Vol. 16, pg. 189-208, http://www.itcon.org/2011/13

Kumar S, Hederick M, Wiacek C, Messner J. (2011). Developing an experienced-based design review application for healthcare facilities using a 3d game engine. Journal of Information Technology in Construction 16:85.

Lin K, Son J, Rojas E. (2011). A pilot study of a 3D game environment for construction safety education. Journal of Information Technology in Construction 16:69.

Mallan, K.; Foth, M.; Greenaway, R.; Young G. (2010). Serious playground: using Second Life to engage high school students in urban planning, Learning, Media and Technology Vol. 35, Iss. 2

Moon, J., Kim, C., Kim, Y., and Cho, K. W. (2008). "CFD Cyber Education Service using Cyberinfrastructure for e-Science." Proc. of the Fourth International Conference on Networked Computing and Advanced Information Management, IEEE Computer Society, Sept. 2-4, 2008, Gyeongju, Korea, pp. 306-313.

Shen, Z., Issa, R, and Gu, L. (2007), "Semantic 3D CAD and Its Applications in Construction Industry – An Outlook of Construction Data Visualization", Advances in Visual Information Systems - Lecture Notes in Computer Science, Springer Berlin / Heidelberg, Vol. 4781, 461-467

Simpson, T. W., Lewis, K. E., Stone, R. B., Reglis, W. C. (2007). "Using Cyberinfrastructure to Enhance Product Dissection in the Classroom." Proc. of the 2007 Industrial Engineering Research Conference, G. Bayraksan, W. Lin, Y. Son, and R. Wysk, (eds), Nashville, TN, May 19-23, 2007, CD-ROM.

Shen Z, Issa, R. (2010) "Quantitative evaluation of the BIM-assisted construction detailed cost Estimates." J. of Information Technology in Construction, Vol. 15, pg. 234-257

Tang P, Huber D, Akinci B, Lipman R, Lytle A. (2010). Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. Automation in Construction 19(7):829-43.

Thompson, C. (2011). Next-generation virtual worlds: Architecture, status, and directions. IEEE Internet Computing, 15(1), 60.

Unity3D (2011). http://unity3d.com/unity/

Vanlande, R., Nicolle, C., Cruz, C. (2008). IFC and building lifecycle management. Automation in Construction 18(1):70-8.

Wang, E., and Shen, Z. (2011). "A Building LCA Case Study Using EcoTech and BIM Model." Associated Schools of Construction 47th Annual International Conference, April 6-9,2011, Omaha, NE

Warburton, S. (2009). Second life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. British Journal of Educational Technology, 40(3), 414.

Zhang, JP. and Hu, ZZ. (2011). BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. principles and methodologies. Automation in Construction 20(2):155-66.