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A system architecture and simulation environment for building information modeling in virtual worlds

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Abstract

This paper describes building information modeling (BIM) research by students and faculty of the University of Nebraska's Peter Kiewit Institute (PKI). The paper also describes work in conjunction with the United States Strategic Command (USSTRATCOM), located at Offutt Air Force Base in Omaha, Nebraska, USA. The objective of this on-going research is to create a virtual modeling environment where architects and planners can present building concepts and design options to customers in a way that is more easily envisioned by the client. The proposed environment would integrate BIM and virtual environments by allowing a free exchange of data between applications. The specific research mentioned in this paper focuses on visualization and editing of interior room configurations for use by USSTRATCOM. The software used for this research project was Autodesk[®] Revit, Autodesk[®] 3DS Max, and a proprietary gaming engine called Unity, developed by Unity Technologies and based in San Francisco, California, USA. This paper covers the development of a system architecture in which BIM will be integrated with a virtual simulation environment built in Science Applications International Corporation's (SAIC's) On-Line Interactive Virtual Environment (OLIVE) and discusses research results to date.

Keywords

Building information modeling, BIM, virtual worlds, virtual environments

1. Background and related research

The Peter Kiewit Institute (PKI) occupies a 192,000 square foot building on the University of Nebraska at Omaha's (UNO's) Pacific Street campus. PKI is home to approximately 85 faculty and 11 academic programs serving 1,800 students from two colleges: the University of Nebraska-Lincoln (UNL) College of Engineering and the UNO College of Information Science and Technology.

In the summer of 2012, the research team wrote a paper summarizing a year's worth of research concerning the integration of building information models and virtual worlds. The specific virtual world used was Science Applications International Corporation's (SAIC's) On-Line Interactive Virtual Environment (OLIVE). This research began when PKI students interested in modeling and simulation established the PKI Society for Computer

Simulation International (SCS) Student Chapter and formed a research partnership with SAIC. Through this partnership, the team gained valuable experience with OLIVE and its many existing applications, including collaboration, training, education, and data visualization. It then became apparent that a potential additional application of OLIVE was architectural visualization. Using a virtual

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world to explore building plans before they are finalized was a significant improvement over traditional architectural renderings because the structure could be seen at any angle instead of at one fixed view point.

OLIVE version 3.0, based on the Unity gaming engine, supports industry standard three-dimensional (3D) model formats such as COLLADA and .FBX. This fact established OLIVE as an excellent platform for the team's research. However, the team did not have access to a OLIVE software developer kit. To overcome this limitation, custom Unity projects were developed that could be easily integrated with OLIVE. The goal of this research was to develop a software architecture that would allow designers and engineers to import building models from building information modeling (BIM) applications into a virtual world and explore them using an avatar. Once the structure is in the virtual world, the software would allow the user to make necessary adjustments and then export the improved model back to the BIM application. OLIVE's collaboration features would also allow other designers or clients to explore the building along with the designer in real time, possibly in completely different physical locations.

A literature review identified various papers on virtual environments used to enhance BIM.¹⁻⁴ The literature review also revealed other applications not directly related to BIM, but which may have relevance to architects, engineers, and educators working in areas such as building sustainability and energy harvesting, first responder training, and interactive on-line education. Alahmad, Nader, Cho et al.,¹ for example, presented research and findings on building information models developed to monitor energy consumption. Ruppel and Schatz³ discussed integrating BIM and virtual environments to create a realistic training simulation where firefighters can practice how to clear buildings or train on firefighting techniques while navigating through virtual buildings. Ku and Mahabaleshwarkar² discussed merging BIM and gaming worlds. Our research team found this approach particularly helpful to our collective understanding of how to couple BIM and OLIVE. Finally, Shen, Jiang, Grosskopf et al.⁴ discussed using Unity as a virtual platform to explore heating, ventilation, and air conditioning (HVAC) systems in virtual worlds and presented their research on educational constructs for achieving intended educational outcome goals using virtual worlds.

Many BIM products utilizing architectural visualization are available in today's industry, including a number of applications specializing in the use of high quality "fly-through" features. Some of these products also incorporate the use of avatars as vehicles for movement and orientation in such fly-throughs. However, the use of avatar exploration as well as the ability to edit the world and then

export changes back into root BIM applications such as Autodesk® Revit has not been accomplished to date.

2. Research objective

The primary goal of this research was to develop a software system architecture that couples BIM and a gaming engine to allow architects and planners to design and develop interior building configurations, based on 3D renderings. The development environments selected for this research were Autodesk® Revit, Autodesk® 3DS Max,⁵ and a gaming engine called Unity developed by Unity Technologies from San Francisco, California, USA.⁶

2.1. Specific research objectives

A major research objective of this project was to create an intuitive, efficient, and user-friendly virtual world tool that allows users to design and modify architectural objects rendered in BIM and then import them into a virtual simulation environment without losing engineering level specifications. This level of detail requires exact management of object attributes such as orientation, position, size, and texture.

Another research objective was to give users the ability to customize building attributes quickly, according to user or client preferences, constraints, or prerequisites. Building design attributes, such as room configuration and layout, as well as interior dimensions and material finishes would be easily and quickly changed or modified by the user.

A final, important objective was to provide users with an ability to collaborate on-line as individuals or groups from distributed locations.

2.2. Significance of research to the engineering and academic communities

Architectural and engineering firms frequently use BIM tools, such as Autodesk® Revit, Autodesk® 3DS Max, and Bentley Building Applications, among others, to design and plan new buildings and for renovation projects.^{5, 7} Architects and engineers also have begun using BIM not only for design processes, but also for showing clients proposed designs in a 3D space that is easy to visualize. Many of these tools, however, are not well-suited for making changes to existing architectural drawings or building designs while presenting such designs to clients. Architectural teams typically work around this problem by creating a number of artistic renderings of the designed spaces for clients, offering multiple options of the finished product. The major drawbacks with artistic renderings are the expense and time required to create or modify them.

This research proposes a new architectural design environment that integrates BIM and a gaming engine to give architects and engineers a virtual world in which to design spaces for clients with an intuitive, natural way in which the spaces can be explored and modified. A new virtual world BIM environment is intended to save architects, engineers, clients, and other stakeholders' time and money by giving them the opportunity to make design changes and explore designed space functionality before construction.

In addition to serving architecture and architectural engineering industries, this research will also benefit academia and educational enterprises. Students studying architecture, architectural engineering, civil engineering, and construction will be well-served by learning more effective ways to visualize and demonstrate important design concepts and processes. The proposed tool would also allow for the simulation of experiences otherwise taught outside the classroom including processes such as construction site safety and the demonstration of how a construction team works safely to finish a project.^{8, 9} Real-life site visits may not be possible due to access restrictions, cost, safety, and the availability of students. Virtual environments will make it possible for teachers and students to examine various layers of building systems in ways that could not be possible using building designs. Virtual classrooms will enable faculty and students to engage on personal and professional levels in ways that chatting, texting, and mobile phones will not support. Virtual worlds have the potential to profoundly make on-line learning more effective because students from all over the world can come together in a collaborative, virtual classroom to learn.

3. Methodology

For this research, the Unity gaming engine was used for development with OLIVE 3.0 being the eventual target platform. Since OLIVE is built using Unity, any software enhancements the team creates in Unity can be transferred to OLIVE 3.0 when the system has matured.

3.1. BIM simulation system prototype architecture

The system architecture in Figure 1 gives a high-level depiction of the major components of the BIM simulation software system. The diagram also illustrates the general process for how system components interact with one another to achieve design goals. Activities of system developers and users involved in the high-level design are also shown, although the diagram does not necessarily portray the sequence of steps in which they occur.

The diagram reflects the research team's current understanding of client requirements for the prototype under

Figure 1. High-level system architecture.

development. It is expected that changes to the system's architecture will occur as users add new requirements or modify the ways that components interact with one another. The processes and interactions between clients, design teams, databases, OLIVE, and BIM are based on use cases developed to date. As additional use cases are explored, lessons will be incorporated into the software system, component design, and the system's architecture.

3.2. Sample process

The team is currently involved in a project with the United States Strategic Command (USSTRATCOM) to use these methodologies to maximize efficiency with existing space constraints in a room that has not yet been built. Although the exact room cannot be shown, a sample room has been constructed to demonstrate the technique and its effectiveness. The goal of this project is to both demonstrate the team's current capability and to develop the capability further into a full-featured product.

Figure 2 illustrates the sample room ready to be exported into a Unity project. The team instantiated the

Figure 2. Sample building shown in Autodesk® 3DS Max.

Figure 3. Sample room in Unity environment.

structure in Autodesk® Revit and then exported it to Autodesk® 3DS Max. Autodesk® Revit is capable of exporting a structure in an FBX 3D format, which can be imported into Unity. However, if additional modeling details, such as textures, need to be added, Autodesk® 3DS Max is an excellent tool.

From this point, the building can be exported in FBX format and easily added to a scene in Unity. Figure 3 shows the building in a simple Unity environment. From this point, additional 3D models can be imported into the project and placed in the environment. Objects, such as tables, chairs, and even servers, can be arranged in such a way as to create different configurations, or scenes. These models can be either downloaded from the Internet or created from scratch.

With these additional models, the research team created several different scenes and integrated them using scripts written in C#. The team also created a corresponding user interface which allows the user to easily switch between

Figure 4. Default configuration.

Figure 5. Conference configuration.

configurations. In Figure 4, a default configuration of the room is shown with computers arranged along the wall. In the Figure 5, a more collaborative, conference room setup is shown. This technique allows planners to see the advantages and disadvantages of a design before the room fixtures have been ordered. With this approach the research team found that the size of furniture, such as tables, may be too big or too small in the original design. This may have gone unnoticed in a two-dimensional (2D) drawing but will be overwhelmingly evident when the room is explored in a 3D environment using an avatar.

An example of a similar situation is shown Figure 6. The room was configured to house a number of servers. When the research team examined the room in the 3D environment, it was obvious that there were too many servers placed into the room. Figure 7 shows an improved version of the room with fewer servers.

Figure 6. Server room.

Figure 7. Improved server room.

4. Results and findings

Through the course of this project, the research team worked closely with planners, architects, and engineers from academia and industry. The team learned a great deal about the design needs and objectives of these communities and identified potential solutions using the proposed BIM software system presented in this paper to meet many of those needs.

The possible solutions identified by the research team included an ability to create, edit, and explore specific interior room configurations. Configuration exploration included unique placement of furniture, interior walls, windows, lighting, and other room accessories, such as television screens, wall-mounted objects, and electrical outlets. With such a tool, it was possible to accurately simulate a classroom or working environment from the

perspective of a person standing or seated in the room itself. Using the perspective of a person allowed for countless configuration approaches. This capability to visualize and edit while running the model was explored by the team and was deemed the most valuable capability from the research effort.

As shown in Figure 4, a corner of the sample room has been furnished with several computer desks and chairs. Once the room was furnished, it was possible to “play” through the scene and explore the room using an avatar. While running the model, the user has the ability to explore the environment from a first-person or third-person viewpoint. These capabilities are paramount to the visualization tool to allow the user to properly see the entire model being explored. Although interior components, such as walls, desks, and other furniture items, are typically placed in the scene before playing, the research team would like to develop the capability for the user of the system to change these attributes while running the model. This capability would greatly improve the visualization and make it simpler to use. It would also decrease the number of man-hours used by the team and thereby reduce the cost for the customers. Currently, the project has been a service-oriented project where the team creates the 3D environment and various configurations for the customer. However, the long-term goal is to develop this research into a software application that is robust enough to be deployed to the customer so that they can make rapid changes to the model as the building plans evolve.

5. Conclusions and future work

The research goals and objectives of this project focused on exploring and creating new ways to improve how architectural and architectural engineering designs created by those who work in these fields are rendered and presented to clients, students, and other stakeholders. Based on the research to date, it is evident that OLIVE 3.0 holds potential as a viable software system to address these issues. The next phase of research will build upon the results achieved to date to further develop and mature the functionality and features of OLIVE 3.0.

Future work to be addressed by the team is as follows:

- develop the current visualization capabilities into more simulation capabilities by adding the ability to simulate functions of a structure;
- develop the capability to export visualized models into 3D BIM programs such as Autodesk® Revit, Autodesk® 3DS Max, or other commercially available 3D BIM applications to allow architects and engineers to quickly make design changes;

- develop the capability to simulate human reactions to disaster scenarios such as building fires by integrating some artificial intelligent avatars; and
- develop the capability to dynamically change attributes of the room by changing specific objects with similar models.

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