BIMGame: Integrating Building Information Modeling and Games to Enhance Sustainable Design and Education

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The ongoing research project develops a new process and related tools to enhance architectural design and education for sustainability. The new process consists of design, play, and update phases. First, in the design phase, designers (professionals or students) use Building Information Modeling (BIM) for representing architectural geometric information and non-geometric information. Second, in the play phase, designers will play games with their designed BIM model. The BIM model is made accessible to educational games through Application Programming Interface (API) of BIM. Both geometric and non-geometric information of BIM are brought into games as content. Game components such as characters (acting as virtual building users), graphics, sound, physics, artificial intelligence, game logic etc., can be added into the games. The games act as a simulation environment for both human activities and physical dynamics in buildings. Designers will be informed about the evaluation of their design in terms of sustainability and about the general design strategies and specific solutions in an interactive and fun way. Finally, in the update phase, the games will allow designers to modify the design and/or the building users’ behaviors/life styles until satisfactory performance is achieved. The design modification will be transferred back into the architectural design through the same API of BIM.

Keywords: Building information modeling; BIM; game; sustainability.
Introduction

Sustainable architecture aims to minimize the negative environmental impact of buildings and provide a high quality of life for their users by a variety of strategies (e.g. using fewer limited resources). In recent years, there has been a high demand for professionals educated to resolve the highly complex social, cultural, technological, and economical issues in sustainable design. The ongoing research develops a new process and related tools to enhance architectural design and education for sustainability.

The main objectives are to:
- Enhance design education for sustainability by integrating Building Information Modeling (BIM) and computer games into architectural design curriculum, and
- Explore how human behavior and life styles, in addition to the physical dimensions such as energy efficiency, affect sustainable design by simulation and gaming.

The new design process for sustainability consists of design, play, and update. First, in the design phase, designers (professionals or students) use BIM for representing vast amount of architectural geometric information (such as room shapes and layout) and non-geometric information (such as materials and building life cycle, which makes BIM systems well suited to address sustainable design and which were not present in conventional CAD systems). Second, in the play phase, designers will play games with their designed BIM model. The BIM model is made accessible to educational games through Application Programming Interface (API) of BIM. Both geometric and non-geometric information are brought into games as content. Game components such as characters (acting as virtual users), graphics, sound, physics, artificial intelligence, game logic etc., can be added into the games. The games act as a simulation environment for both human activities and physical dynamics in buildings. Designers will be informed about the evaluation of their design in terms of sustainability and about the general design strategies and specific solutions in an interactive and fun way. Finally, in the update phase, the games will allow designers to modify the design and/or the building users’ behaviors/life styles until satisfactory performance is achieved. The design modification will be transferred back into the architectural design through the same API of BIM.

The significance of this research lies in the following aspects:
- Enhancing design education for sustainability by changing the current sustainable design education process from ‘design-evaluation-update’ to ‘design-play-update’.
- Advancing the research of applying BIM in sustainable design. BIM is an emerging solution for the interoperability among Architecture, Engineering, and Construction, and it is expected to be well suited for sustainable design and this subject is worth more research.
- Advancing the research of applying games to environment-behavior simulation and to evaluation of architectural design performance. The research is addressing the problem of predicting and evaluating the impacts of the built environment on its human inhabitants by environment-behavior simulation.
- Exploring and evaluating the seamless integration of the two major players in design and learning – BIM and games – into effective teaching and learning activities related to sustainable development in the architectural design curriculum.
- Motivating design students and professionals to learn sustainable design strategies by game-play in their own designed environments, and share and apply the strategies in design projects. This will ultimately assist in achieving a more sustainable built environment.

Background

Sustainable architecture aims to minimize the negative environmental impact of buildings by using less energy and fewer limited resources, eliminating
pollution, employing reusable materials, and efficient use of space. In recent years, there has been a high demand for professionals educated in sustainable design (http://en.wikipedia.org/wiki/Sustainable_design, May 2007) and the number of degree programs in this discipline is increasing. A Decade of Education for Sustainable Development has been initiated starting from 2005 by The United Nations with special reference to interactive methods in education and training (http://www.unesco.org/education/desd/, May 2007).

However, the complex nature of sustainability which involves social, cultural, technological, and economical issues caused strong resistance to adopting sustainable practices and led to difficulties in sustainable design education (Unruh, 2002). “Numerous barriers to sustainability arise because today’s technological systems and governing institutions were designed and built for permanence and reliability, not change” (Unruh, 2002). How to educate next generation designers about sustainable design remains a complex problem.

Meanwhile, on one hand, architectural design community and design curriculum start to migrate from Computer-Aided Design, which is focused on the geometric modeling, to Building Information Modeling (BIM), which is the representation of both geometric information and non-geometric information (e.g. usability information, material information, and the building process) to facilitate exchange and interoperability of information in digital format. With BIM, a building model is done by creating real world objects like columns, walls, and doors into the model, instead of mere graphics symbols representing only geometrical properties of architectural elements as in conventional CAD systems. Theoretically, these BIM models will provide all related data to the designer describing the geometry, as well as any related data associated with how the object is actually used (Ibrahim and Krawczyk, 2003). Therefore BIM facilitates complex simulations and analyses that were previously difficult to perform. As BIM systems are adopted steadily more and more in the building industry and academia in the recent years, sustainable design solutions start to emerge with BIM systems. For example, Autodesk Revit Building software provides a solution that supports sustainable design with IES’ VE (images.autodesk.com/adsk/files/bim_for_sustainable_design_jun05.pdf; May 2007; www.iesve.com: May 2007).

On the other hand, computer games as an effective learning tool have been used in education for decades. In design education, computer games have been used in visualization and collaboration, e.g. Lehtinen (2002) and Moloney (2005). In terms of sustainable architecture, design becomes a complex task that requires a good understanding of the issue and strategic solutions (Shu-Yang, et al., 2004; Anastas and Zimmerman, 2003). For example, during the design process, strategies and decisions about many different choices need to be made for building placement, materials, waste management, energy use etc. At the same time the design is required to help achieve an economical balance between long term cost and short term investment for the buildings and between individual and collective interests. This process in many ways mimics a game play and therefore the topic of sustainable design is well suited for a game. Recently games have been developed for education in sustainable development issues targeting general audience (e.g. Torres and Macedo, 2000; http://www.mysusthouse.org/, 2007).

However, a major problem exists when we try to use games for educating sustainability targeting design professionals and students: how to combine the building models into games for evaluating buildings’ sustainable performance. With conventional CAD models, the process requires expensive manual translations that brings the models into specialized evaluation software, e.g. for energy consumption simulation, a human operator is needed to identify and distinguish the various building components, before the simulation program can run (Kalay, 2004). Our research is therefore to develop a solution of integrating BIM and games to change and enhance the design education process.
Research design and methods

The major research activities are focused on the development of the new sustainable design process: *Design-Play-Update*. The process is illustrated in figure 1. The process and the associated research activities are described below.

**Design phase**

The process starts from the *design* phase. Designers conduct architectural design according to design specifications, including site information, the usage of spaces, building codes, sustainable requirements etc. BIM is used by the designers during the design process for constructing 3D models of buildings.

The research activity associated in this phase is to find how to effectively use the current BIM systems for sustainable design, and to find what are missing in the BIM systems for effective sustainable design and suggest improvement solutions. In future evaluation of the system, both the design process and the products (BIM models) will be analyzed to identify the application of BIM in sustainable design.

**Play phase**

In the *play* phase, sustainable games are being built by our system using the BIM model as environment content. Virtual building users (characters) and other game components such as graphics (e.g. shaders and camera views), audio, physics, artificial intelligence etc. will be added into the games. Designers will play the games and the system can produce simulations of both physical performance of the buildings and behaviors of virtual users. The research activities associated with this phase include the following:

1. Developing a software module that facilitates data access and interoperability between BIM and games. BIM will act as a central database for vast amount of architectural geometric information and non-geometric information. The database is accessible to the games through Application Programming Interface (API) of BIM. The software module acts as a communicator between BIM and the games. It
allows the games to retrieve the building information to be used in the games and also allow the updates of building elements to be transferred back to the building model (figure 2). The module has the following functions:

- Access all building elements in the building information model
- Query building element properties
- Change building element properties
- Add new building elements to the model
- Remove existing building elements from the model
- Access all game components
- Query game component properties
- Change game component properties
- Add new components to the games
- Remove existing components from the games

2. Modeling virtual building users in games. Occupant life styles and satisfaction will greatly affect sustainability and strategies of sustainable design. For example, given a house design, different household strategies will result in different sustainability performance including energy and resource consumption. It is important to consider, model, and evaluate the life styles and behaviors of users for building design to achieve sustainability. Users will be modeled as autonomous agents (called Virtual Users (Yan and Kalay, 2006)) that emulate the appearance, perception, social traits and physical behaviors of real users. Their behavior model will be based upon theoretical and practical environment-behavior studies and real world data. By inserting the virtual users in the building model within the game environment, and letting them “explore” it on their own volition, the system is expected to reveal the interrelationship between the environment and its users and to reveal the performance of sustainability.

3. Developing sustainable games. Game topics and game levels (game sections with different difficulties) will be developed. Sample levels include: playing different life styles, balancing resource saving strategies and occupant satisfaction, decision-making about building materials and budget etc. Players will need to meet specific goals or perform a specific task to advance to the next level. Both training and evaluation sessions will be included in the game.

4. Modeling physical building performance in games: The system will incorporate existing tools (e.g. IES’VE) for simulating and evaluating the use of energy and resource in buildings, which is an essential part of sustainability evaluation.

**Update phase**

In the *update* phase, based on physical and life simulation, the system will conduct evaluation of the building design using sustainability criteria, e.g. LEED Rating System. Game score and sustainability performance will be shown to the players and suggested strategies and solutions for potential problems in terms of design changes and/or life style changes will also be provided. Designers can experiment with the suggested solutions and/or their own solutions in the game environment until satisfactory game scores are obtained. The solutions will be transferred back to the building information model to update design and/or to update specifications. The whole design process ends with updated design and specifications. Research activities associated with this phase include:

1. Evaluation of sustainability. A software module will be developed to evaluate the sustainability performance based on building impacts to the environment and occupants’ satisfaction.

2. Modification of buildings in the game environment: A software module will be developed to modify the buildings inside the game. For design process efficiency, it is expected that the players can modify the buildings within the game environment until satisfactory sustainability performance is achieved and the system can transfer the updates back to the design. This is better than letting players make changes in the original design, play the game, evaluate the performance again – a process that may need to be repeated many times.
Preliminary prototype and sample scenarios

We have developed a preliminary prototype system to demonstrate the integration of BIM and game in the context of architectural design.

At the conceptual level, the design of the system will not be tied to any specific software packages of BIM and game engines. In the current research scope, however, two existing systems are chosen for the system to work with: Autodesk Revit, which is a popular BIM system in the design community, and Microsoft XNA Game Studio Express (XNA), which is a freely available game development environment that provides a set of tools with a managed runtime environment to facilitate computer game design, development, and management. The games built with XNA can be played on both computers and game consoles - Xbox 360’s.

In Revit there are three levels of component parameters: family, type and instance. The family parameters define the general information of components, e.g. a door could be “Double Glass”; the type parameters could be 36” x 84”, and the instance parameters are the unique information, such as the door location and the door mark. In addition to the built-in parameters, users can also define new parameters. The parameters can be accessed through Revit’s API, which is used in our system for building the communicator to access the building information model because it enables all the functions of the communicator to be implemented. API is a

Figure 3
Upper left: Revit BIM model of a sample architectural design (by Autodesk, Inc.); Upper right: properties of a selected door – Door #8 with two user-defined parameters, “Room1” and “Room2”, which are instance parameters of doors. Door #8 connects Room #2 and Room #3, so “Room 1” value is #2 and “Room 2” value is #3. This door-room relationship is used for calculating the shortest path. Lower left: interactive form allowing designers to select the source and destination rooms, e.g. from Room #1 to Room #4. Lower right: the building model is transferred into a game environment and a character is added into the game. He walks from Room #1 to Room #4 on a path calculated by a shortest path algorithm. Later, a change is made in the architectural design – Door #4 is removed and the character can walk along a different path from Room #1 to Room #4 according to the design change.
programming tool that allows applications (e.g. cost estimation software tools and games) to access the building information model. For example, a room in a building information model has the following properties: area, room center’s X, Y, and Z coordinates, enclosing walls, associated doors etc. and a door has the following properties: height and width, location’s X, Y, Z coordinates, which two rooms it is connecting, etc. These properties can be accessed by external programs (games) through the API. In addition, the API can also allow users to access the currently selected elements.

XNA Framework – libraries of game programming functions – is used for the system to create game components using building information models and pre-defined components such as audio, physics etc.

**Scenario 1: Simulating virtual user’s path-finding in a game**

As an example, the system can retrieve room and door information from a building information model that has been created in the design phase and can use the information for path-finding and visualization of a game character’s walking behavior in the play phase (figure 3). The simulation is realized by the following process:

1. Retrieving/calculating the coordinates of room centers and doors of the Revit model through Revit API.
2. Extracting the user-defined “connected rooms” parameter for each door. For example, the Door #8 connects Room #2 and Room #3, so for this door, its parameter “Room 1” value is #2 and parameter “Room 2” value is #3.
3. Creating a weighted graph for Dijkstra’s shortest path algorithm regarding the rooms as vertices and center-to-center paths of connected rooms as edges.
4. Calculating the shortest path using user-selected source and destination rooms.
5. Running XNA game thread and pass the calculated path to the character model.
6. Animating the character to make him walk along the path in the building model.

Currently, the building model is imported to XNA via 3DS Max from Revit. The “connected rooms” parameter of a door is a user-defined parameter and has to be entered manually in the BIM model. We suggest that this and other similar intrinsic parameters of building components to be added by BIM software developers as built-in parameters that can return proper values automatically to facilitate external applications.

**Scenario 2: Transferring material change back to BIM model**

A sustainable game is expected to provide general design strategies and specific solutions for the designers in the context of the current design. In a sample scenario, the update phase will allow the change suggested by the solutions to be transferred back to the BIM model. This change has been realized through the following process:

1. XNA passes a new material value of interior walls – “wood” - to Revit API.
2. Revit API accesses the BIM model’s interior walls material parameter and rewrites the value of the parameter from the existing one (“concrete”) to “wood”.

This is a simple scenario demonstrating the concept of updating the BIM mode from games.

**Conclusions and future work**

The project is an ongoing project that is expected to produce a new education strategy to enhance sustainable design and education using integrated BIM and games. Sustainable games need to be developed and a complete system is expected to be built and evaluated in architectural design courses. To promote sustainable development to architectural design students and professionals worldwide, a web-based digital library is planned for exchanging educational game components, networked games, and design strategies for sustainability.
References