

# Environment-Behavior Simulation

## From CAD to BIM and Beyond

Behavior  
BIM

Environment

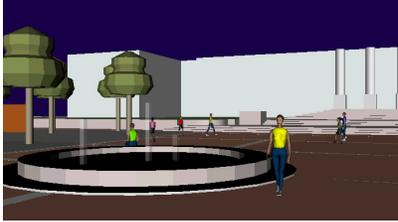
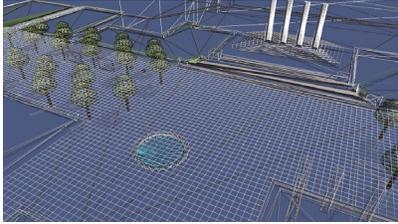
Information

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THIS PAPER DESCRIBES OUR RESEARCH ON ENVIRONMENT-BEHAVIOR SIMULATION AND FOCUSES ON THE MODELING OF BUILT ENVIRONMENTS USING COMPUTER-AIDED DESIGN (CAD) AND BUILDING INFORMATION MODELING (BIM). Our environment-behavior simulation addresses the problem of predicting and evaluating the impacts of built environments on their human inhabitants. We present simulation systems comprising an agent-based virtual user model and building models created with CAD and BIM tools. We compare the use of CAD vs. BIM with two case studies for environment-behavior simulation, and describe the essential parts of modeling buildings for the simulation, including geometry modeling—how the building components are shaped, semantic modeling—what the building components are, and pattern modeling—how the building components are used by users. We conclude that a new extensible and pattern-embedded BIM system will be necessary to facilitate environment-behavior simulation.

Simulation



## 1 Introduction

Simulating users' behaviors in built environments is important for predicting and evaluating buildings' performance before the buildings are built. Considerable empirical research helped develop the requisite cognitive models for existing human spatial behavior simulations, including pedestrian traffic simulation (e.g. Helbing et al. 2001; Haklay et al. 2001), fire egress simulation (e.g. Stahl 1982; Ozel 1993, and Pan 2006), and general human spatial behavior simulation models (Archea 1977, Kaplan & Kaplan 1982, Batty 2001, and Thalmann & Musse 2007).

Both a model of virtual users and a model of built environments are keys to environment-behavior simulation whose goal is to evaluate the environments' effects on human behavior. We have modeled virtual users as autonomous agents that emulate the appearance, perception, social traits and physical behaviors of real users (Yan and Kalay, 2006a). The virtual users' behavior was modeled based upon theoretical and practical environment-behavior studies, real world data from field studies, and Artificial Life research (Reynolds 1987). By inserting the virtual users in building models, and letting the virtual users "explore" the buildings on their own volition, we expect our simulations to be able to reveal the interrelationship between the built environments and their users.

Our focus of this paper, however, is on the modeling of built environments, while the virtual human modeling has been researched by us and also other researchers extensively through crowd behavior simulation, steering behaviors, and pedestrian modeling (e.g. Thalmann & Musse, 2007, Reynolds, 2006, Batty, 2001, and Yan and Kalay, 2006a).

Built environments are fairly complicated, compared with environments of the kind used in Artificial Life simulations, where autonomous life-like agents fly in the sky or swim in a tank with certain motivations and according to certain behavior rules. For example, the Boids (Reynolds 1987) environment consisted of empty spaces and obstacles and the simulation was focused on simulating the interaction among bird-like agents during their flight, while avoiding obstacles. Similarly, the artificial fish (Tu 1996) environment consisted of water current, seaweed and plankton. The fish were able to perceive their environments and act by avoiding collisions and pursuing a moving target. In contrast, built environments consist of a large number of design elements, such as rooms, walls, doors, windows, stairs, columns, benches, fountains, lawns, paving, etc. A virtual user needs to perceive and understand all of them in order to behave properly, e.g. walk through a door, stand by a fountain, and sit on a bench.

The following different kinds of information from building models will be necessary for virtual users to understand their building environments: geometric information—how the building components are shaped, semantic information—what the building components are, and pattern information—how the building components are used by users. Throughout the paper, if not noted otherwise, the term 'pattern' refers to how the building components are used by users and this reference can be regarded as following the pattern described in *The Pattern Language* (Alexander, et al. 1977) but limited to a much more specific scope.

Geometric modeling, semantic modeling, and pattern modeling are essential parts of building modeling for environment-behavior simulation. By default, Computer-Aided Design (CAD) modeling represents geometric information, and Building Information Modeling (BIM), as an emerging technology, represents and allows easy access to building information including both geometric information and semantic information. However, pattern information, in the context of behavior simulation, is not embedded in BIM (Ozel 2007), not to mention CAD.

Currently, for environment-behavior simulation, the models of built environments are made mostly using CAD tools with geometric modeling capabilities. For example, Pan (2006) used his Geometric Engine to produce the geometries representing the physical environments (e.g. a building or a train station) and spatial information, including obstacles, exits, spaces, etc., was defined using CAD tools such as AutoCAD/ADT (Architectural Desktop Software).

Semantic information and pattern information need to be added into CAD models man-

FIGURE 1. CAD MODEL OF THE PLAZA

FIGURE 2. SIMULATION RESULTS. (SOURCE OF HUMAN MODELS: BALLREICH, 1997)

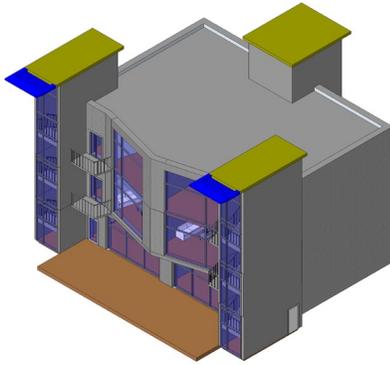


FIGURE 3. BIM MODEL OF AN APARTMENT BUILDING. (SOURCE: SAMPLE MODEL OF AUTODESK REVIT ARCHITECTURE 2008.)

FIGURE 4. FLOOR PLAN OF THE BUILDING MODEL.

ually, e.g. through tagging for the different zones of virtual worlds that were created using geometry modeling (CAD) tools to simulate crowd behavior (Yersin, et al. 2005).

BIM-based 3D models now started to be used for crowd simulation (Eastman, et al. 2008), but the current use is focused more on accurate 3D geometry modeling that BIM can provide, than on the utilization of semantic information also provided by the BIM models. As pattern information is not embedded in the current BIM models yet, the use of it in BIM for environment-behavior simulation has not been investigated.

In this paper, we discuss our two different approaches for building modeling, their resulting simulations, and their applications. As CAD is still actively used in the design community, in this paper, we first discuss our CAD-based approach for environment-behavior simulation in Section 2, as a comparison to our BIM-based approach, which will be discussed in Section 3. We further discuss the limitations of BIM and propose pattern-embedded BIM for the simulation in Section 4. We conclude and state our future work in Section 5.

## 2 CAD-based Simulation

CAD-based simulation utilizes existing geometries from the CAD models, but normally requires manual input of semantics (meanings of objects) and patterns (how objects are used by users). With a conventional CAD model, evaluating a building's performance requires expensive manual translation that brings the model into specialized evaluation software (Kalay, 2004).

However, CAD is still widely used in the design community, though BIM is becoming a new trend. Therefore solutions for CAD-based simulation are needed. Also, current BIM systems can't easily produce free form geometries and CAD has to be used when free form design is desired. In some cases, complex building forms make it difficult to distinguish semantics such as walls or roofs if the building components are sloped, in which case BIM is limited in providing added value of semantics. In addition, for conceptual design phase simulation, concerning only forms but not semantics, CAD tools like SketchUp have their advantages over BIM tools. Therefore CAD-based simulation will still have an important value.

Following the above arguments, we describe below a *CAD-based simulation prototype*, focusing on the integration of geometry modeling, semantic modeling, and pattern modeling, using a case study of a plaza to illustrate our modeling approach. A detailed description about the building modeling approach can be found in Yan and Kalay (2006b).

### 2.1 GEOMETRIC MODELING

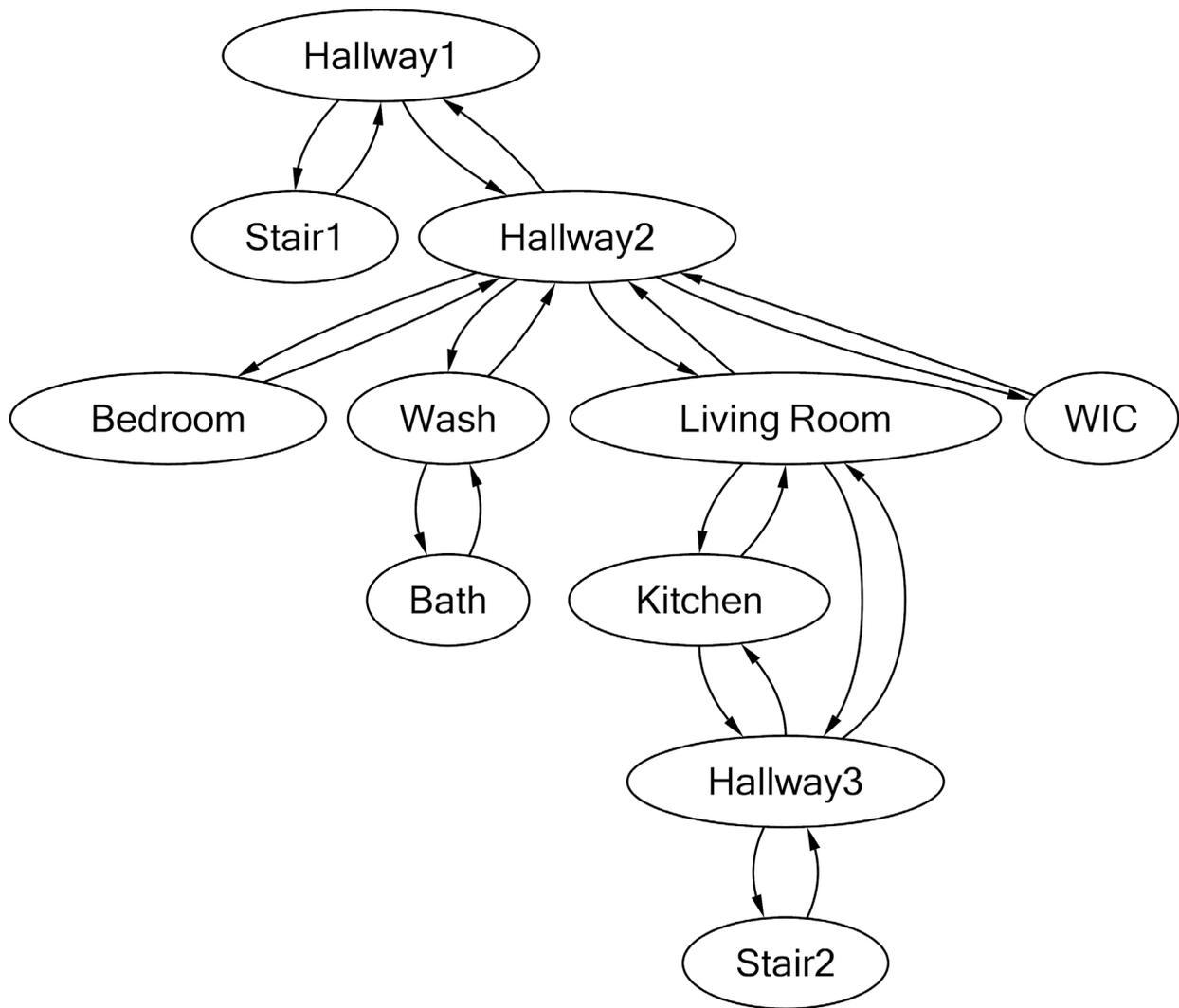
Our geometric models are built on top of existing CAD models. Such building models already contain complete geometric information. For our case study, we created a model of a plaza in layer-based DXF format, and converted it into a discrete 2D model for simulation and a 3D (VRML) model for visualization (Figure 1 and Figure 2).

### 2.2 SEMANTIC MODELING

CAD models lack semantics of objects—what design elements they represent—and therefore cannot be understood by virtual users. Our system assists in inserting semantic information of design elements into the CAD models by converting the DXF into Scalable Vector Graphics (SVG) format, which is a format for describing two-dimensional graphics in XML (W3C Recommendation). SVG is semantically rich: the graphical information is always associated with meaningful textual information. In our approach, as the geometries in the DXF format are converted into SVG elements, their architectural semantics (e.g. LowWall) are inserted into the SVG element-tree according to their layer names, which we added in CAD modeling.

### 2.3 PATTERN MODELING

Attributes can be added into each SVG element. We add patterns as attributes to each element in the SVG model. Our SVG model's element-tree can be traversed to search for a specific node, which can be checked for attributes. In our approach, as architectural semantics are inserted into the SVG element-tree, custom tags of the architectural components with their attributes (patterns), appear in the data structure. For example, the four-



tain-side element is defined by its element type, having its patterns (e.g. sittable), followed by its geometry element.

#### 2.4 SIMULATION RESULTS

Our building model integrates geometry, semantics, and patterns, and therefore allows virtual users to access and understand the space's properties, beyond mere geometry. The simulation results demonstrates virtual users' movements, including walking and standing in the plaza, sitting at different places, etc. as seen in Figure 2.

### 3 BIM-based Simulation

With BIM, a building model is built by creating real world objects like columns, walls, and doors, instead of mere graphic symbols representing only geometrical properties of architectural components as in conventional CAD systems. Being a more complete data model, BIM facilitates complex simulations and analyses that were previously difficult to perform (Seletsky, 2005).

In BIM, geometric modeling and semantic modeling are integrated, making it currently the most appropriate environment modeling platform for simulation. However, it still lacks patterns. Using a second case study in this paper, we demonstrate our BIM-based modeling, including geometric modeling, semantic modeling, and added pattern modeling, showing advantages and limitations of BIM-based modeling compared to CAD-based modeling.

FIGURE 5. ROOM CONNECTIVITY GRAPH.

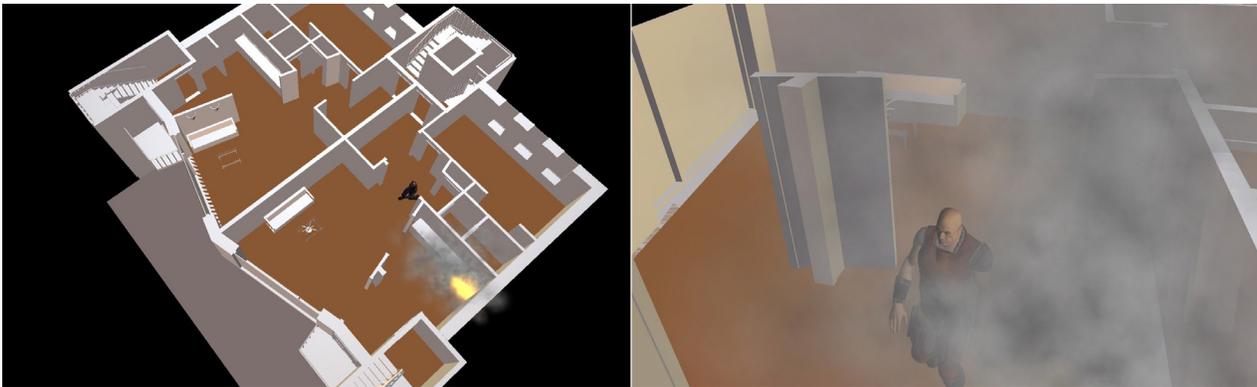
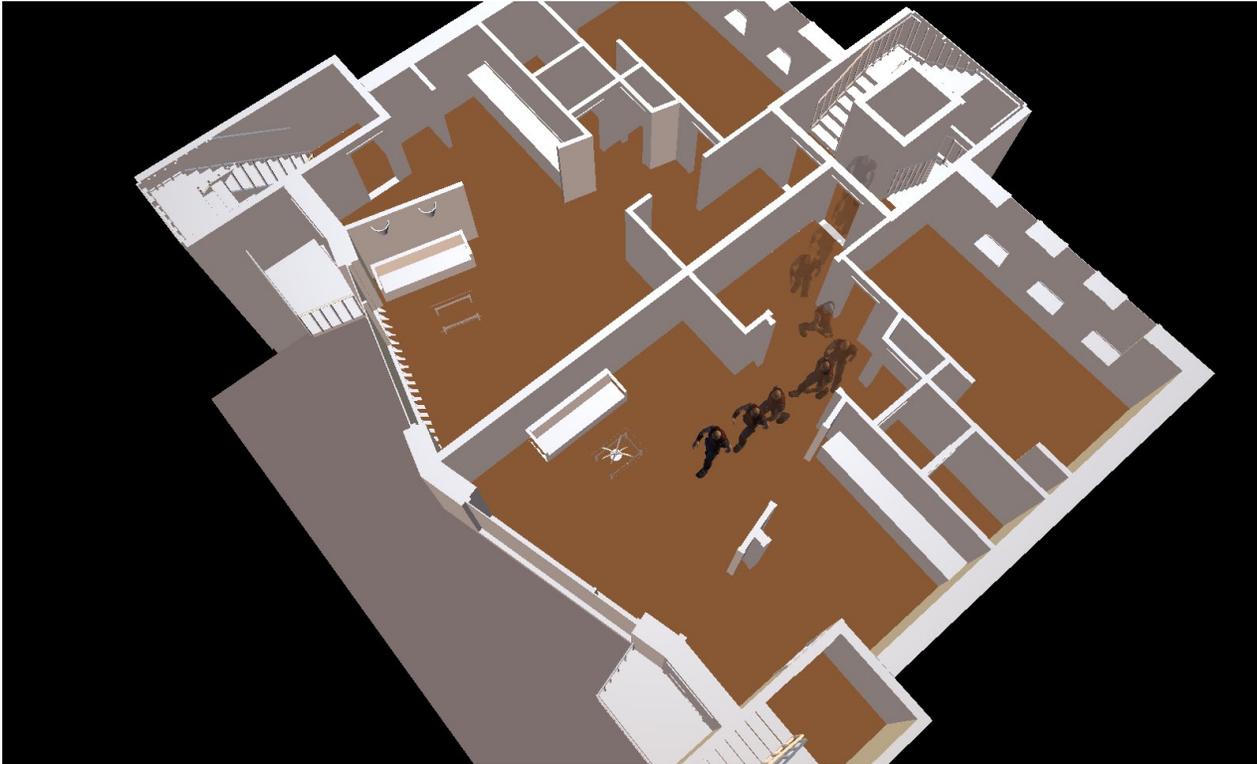


FIGURE 6. A VIRTUAL USER WALKS THROUGH THE APARTMENT.

FIGURE 7. FIRE SIMULATION IN THE BUILDING. (SOURCE OF THE HUMAN MODEL AND THE FIRE MODEL: MICROSOFT XNA SAMPLES AT [HTTP://CREATORS.XNA.COM/](http://creators.xna.com/))

### 3.1 GEOMETRIC MODELING

BIM's geometric modeling is targeted at the high-level of 3D geometries of building components, and compared to CAD modeling tools, existing BIM modelers' geometry modeling capabilities are limited at the low-level of direct manipulations of points, lines, and surfaces (Greenwold and Driver 2007). In other words, for geometric modeling, BIM modelers work well when the building geometries are of regular forms. Otherwise, importing CAD geometries into BIM is often needed for BIM geometric modeling. This is especially true for free form modeling, e.g. tilted walls, or roofs of NURBS geometry.

In this case study, we used Autodesk Revit (a BIM modeler) and a sample model of an apartment building for testing our approach (Figure 3).

### 3.2 SEMANTIC MODELING

BIM integrates semantic information into geometric information by asking users to specify what type of an object, e.g. a wall, a roof, or a window, along with what shape of the object, they are going to build in the models (Greenwold and Driver 2007). The semantics comes from the architectural domain-specific knowledge embedded in the modelers.

In case the geometries are converted from CAD models, their semantics needs to be added by using BIM functions that can create building components such as walls, roofs,

curtain walls, etc., based on geometric faces. However, for buildings of regular forms, default ways of modeling integrating geometry and semantics suffice.

In our case study, the semantics we used included: rooms (bedrooms, living rooms, kitchen, etc.), walls, and doors. Based on the BIM model's geometric and semantic information, our system can generate a room connectivity graph with rooms as nodes and doors/openings as edges (Figure 4 and Figure 5). The graph enables path-finding algorithms to be used for path-planning in our simulation.

### 3.3 PATTERN MODELING

In current BIM, the patterns that we are interested—how users will use the designed spaces and objects—are not embedded in the models. Therefore, in our case study, we added user-defined parameters to building components to embed simple use patterns. For example, in our model, a room in a building information model has the following properties: built-in parameters such as the area and room's enclosing walls, and user-defined patterns: allowing virtual users to stay and walk in it. A door has the following properties: built-in parameters such as height, width, and location, and user-defined patterns: allowing virtual users to exit a room and enter another room.

BIM's built-in geometry and semantics, and user-defined patterns can be accessed by external programs (e.g. simulation applications) through Application Programming Interface (API)—a programming tool that allows external programs to access the BIM model. We have developed a software module based on Revit API and used it to facilitate data access between BIM and our simulation program.

### 3.4 SIMULATION RESULTS

In this case study, our system can retrieve room, wall, and door information including geometry, semantics, and patterns from a BIM model and can use the information for path-finding simulation and visualization using a simulation engine we built with Microsoft XNA Game Studio Express—BIMGame (Yan and Liu, 2007). In Figure 6, a virtual user walks through the apartment entrance door and a series of spaces and enters the living room. Multiple screenshots of the simulation result are superimposed in the figure to indicate the user's walking path.

The case study also allows inserting different kinds of simulation components, e.g. fire simulation (Figure 7).

Though the behaviors simulated in the case study are simple, the study demonstrates the BIM-based environment-behavior simulation approach and its potentials. More complex patterns will enable more complex behavior simulation. Therefore we propose in the next section a new BIM system with dedicated patterns modeled and embedded in the system.

## 4 Pattern-embedded BIM

Compared to CAD where only geometric information (how the building components are shaped) exists, semantic information (what the building components are) has been integrated into BIM systems, which made BIM currently the most suitable building modeling approach for environment-behavior simulation. However, as we have stated previously, pattern information (how the building components are being used by users) is also an important part of building modeling for environment-behavior simulation. According to Ozel:

*This (BIM) has been mostly as a result of concern for interoperability. The key difference between these efforts and 'pattern language' is that while the former approaches the issue as an effort to model real world objects in a value free, impartial way, Alexander (1977) intends to include his experiences as a designer into the framework in the form of 'patterns' that include rubrics to summarize design rationale.*  
OZEL (2007)

Following this statement and based on our simulation research, we propose a pattern-embedded BIM system for environment-behavior simulation. The system models not only

how the building components are shaped and what they mean in real world, but also how they are going to be used by users.

The implementation of pattern embedding will involve designing a dedicated pattern database that is accessible like the current BIM components' properties.

Designers' personal experience/knowledge will contribute to the patterns (Ozel 2007). For example, Alexander described the patterns of a sitting wall between outdoor spaces:

*A low wall or balustrade, just at the right height for sitting, is perfect. It creates a barrier which separates. But because it invites people to sit on it—invites them to sit first with their legs on one side, then with their legs on top, then to swivel round still further to the other side, or to sit astride it—it also functions as a seam, which makes a positive connection between the two places.*

ALEXANDER, ET AL. (1977)

For the same building component, e.g. a low wall, different designers will have different views about how it is going to be used by users, which should lead to different behavior simulation results.

This is a challenge to the design and implementation of the pattern-embedded BIM system. The system needs to be open and extensible—allowing designers, users, and behaviorists to input specific patterns based on their experience and knowledge, in addition to the built-in patterns that represent general uses of building components.

With patterns embedded, we expect that Building Information Modeling will possess not only physical building information, but also social and cultural information of architecture.

## 5 Conclusion and Future Work

In this paper, we have presented our CAD-based and BIM-based building modeling approaches for environment-behavior simulation with cases studies. We have discussed both advantages and limitations of the two approaches. We proposed a pattern-embedded BIM system to facilitate environment-behavior simulation. In our future work, we will investigate the design, implementation, and evaluation of a pattern-embedded BIM system.

## 6 Acknowledgements

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