Environmental Design eTutor

Utilizing Games Technology for Environmental Design Education

Ahmed Sarhan¹ and Peter Rutherford²
¹,² Department of Architecture and Built Environment, University of Nottingham, UK.
¹,² http://www.nottingham.ac.uk/sbe
¹ laxas4@nottingham.ac.uk, ² Peter.Rutherford@nottingham.ac.uk

Abstract. The design paradigm has shifted from addressing geometric masses and social spaces to integrate a whole new set of variables and criteria evolving from the environmental aspect of the design. Architectural design is confronting a mounting challenge with the ever-growing complexity of design concepts and the increasing pressure to incorporate aspects of energy preservation and sustainability. Such challenge is clearly noted and sensed within the pedagogical realm. There are many calls to bridge the gap through assisting design students to assimilate environmental analysis data in their design and decision making process. This paper presents a framework for a proposed method and relating tools aiming to utilize games technology with multi-agent systems and data mining techniques to assist design students and untrained professionals in comprehending various aspects of environmental design, with guidelines to incorporate these aspects in their design iteration process.

Keywords. Environmental Design Education; Building Performance Simulation; Games Technology; Multi-Agent Systems; Data Mining.

INTRODUCTION

The United Nations has instigated a new ‘Decade of Education for Sustainable Development’ back in 2005, aiming to educate and prepare a new generation of young professionals (including architects) for lower energy needs and preservation of natural resources (Yan and Liu, 2007). With the ever-growing call for green and environmental-friendly designs, there has been a high demand for designers to resolve the highly complex social, cultural, technological, and economical issues in “Sustainable Design”. This new trend has evolved the traditional design method from just the formulation of masses and social spaces, to introduce a series of new complex variables and equations that the proposed design should fulfil and resolve to become acceptable. Design students are thus facing bigger challenges to develop their conceptual ideas while accommodating these new variables, and developing a design that satisfies both the visual and technical parameters. The challenge now falls on the schools of architecture to prepare new generations of designers that are capable to address both sets of design variables, with high level of comprehension of all presented parameters, and solid approach to problem analysis and decision making.

This paper presents a proposed method -with the relating tools- that seeks to facilitate the integration of environmental design into the architectural
design process. The paper discusses the currently noted pragmatic issues with using Building Performance Simulation (BPS) applications in the architectural community, and proposes to employ games technology with Multi-Agent System (MAS) and Data Mining (DM) techniques to develop a supplementary tool that assists architects and attempt to resolve these issues.

ENVIRONMENTAL DESIGN

BPS applications offer new frontiers for the architectural community to investigate further dimensions in their designs that extend far beyond the aesthetical qualitative nature. These applications aim to be effective decision-support system and design validation tool, through providing sophisticated analysis and methodical evaluation of anticipated design-specific performances. The analytical evaluating temperament is particularly suitable for the iterative nature that architectural design process possesses (Bambardekar and Poerschke, 2009), where the repeated gradual refinement of design entities and details can be reflected in its anticipated performance. In the architectural pedagogy, BPS applications, as argued by Charles and Thomas (2009), can offer design students a chance to broaden their perspective and skill set, gaining constructive analysis proficiency with regards to complex building physics phenomenon.

Currently there are number of BPS tools employed by architects at various stages of design (like Ecotect, IES-VE, EnergyPlus, etc). However, the highly technical nature of these tools has generated several pragmatic issues for their use within the architectural community, particularly with students and untrained professionals. There is a high risk with the misuse of BPS tools, leading in turn to misleading results and subsequently uncalculated design decisions that can ultimately affect the building’s performance throughout its lifecycle. The pragmatic issues noted with BPS integration in the architectural design community can be divided into three sections:

Motivation to use BPS applications

One of the key aspects affecting architects’ approach to environmental design is their constant desire to freely explore and design concepts. Soebarto (2005), among many others, argued that architects in general place the environmental aspects of their design at a much lower priority level, while the aesthetical aspect of design is generally acquiring the higher priority in the design process. Design students tend to think more about geometries, masses, proportions, as well as social interaction with and within the space. On the other hand, they perceive environmental design as a series of mathematical equations that requires extensive time and effort to resolve, and this is a medium they are not naturally accustomed to, thus taking them out of their comfort zones. The new criteria introduced to the design process are perceived to be extra burdens, and thus could hinder the architects’ creativity.

Another aspect affecting architects’ motivation to use BPS tools is the level of detailed information required before initializing the simulation. At the preliminary conceptual design stages, details are generally in an abstract format and thus deemed insufficient to run the performance analysis, particularly as the building geometry is under constant updating and modification. This fact, as argued by Mahdavi (2005), caused architects to recede from using BPS tools in the important early stages of design, relying only on the final validation at the later stages when the required information are available (in many cases run by specialists and service engineers).

Motivation to use BPS is also affected by the architects’ preference to rely on experience and guidebooks. Struck and Hensen (2007) argued that

“Design decisions are often based on experience and intuition, rather than on quantitative prediction of performance indicators such as running costs, thermal comfort and CO2 emissions” (pp.1434).
Pedrini and Szokolay (2005) also concluded that in early design stages, personal experience and intuition are the most preferred methods for architects, followed by rules-of-thumb, design guidelines, and published design assisting suggestions, while mathematical simulation models are among the least favored.

**Complexity of BPS applications**

For a simulation process to be effective, designers need to possess a good level of knowledge and understanding to be able to formulate and define a set of criteria and procedures that structure the building simulation and analysis process. Designers need to clearly specify the assessments routines required to run in the BPS tool they are employing, based on the desired outcomes they envision to obtain. It is arguable that the complex, highly technical nature of most BPS applications (in terms of interface and functionality) results in a steep learning curve that faces the architects. A study carried out by Soebarto (2005) concluded that architectural design students spent a lot of time and effort trying to prepare and run the simulation on their designed model. The process required interventions from instructors and studio tutors to provide support and further rationalization about different particulars in the simulation program, and the basics of calculations. In another study, Bambardekar and Poerschke (2009) observed that students tend to invest extensive amount of resources and time, looking for explanations, examples and documentations, to be able to understand the basic environmental analysis concepts, particularly when -in most cases- not one BPS application was sufficient enough to perform a full comprehensive simulation, and answer all design inquiries.

**Knowledge extraction and data representation**

The key objective behind using BPS tools is to formulate informative decisions that improve the proposed building design performance. Misinterpretation of simulation outcomes could lead to clear failure to translate obtained data to design criteria and thus effectively iterate the design. Srivastav et al. (2009) argued that this could be based on the ineffectiveness of current BPS means of visualization, due to the complexity of representation of analysis data, and thus the difficulty in correlating the data, defining patterns, ... causalities, and extracting knowledge. The outcomes of the simulation process are normally non-geometric quantitative data, represented by different numerical, tabular, and graphical means (including layering, colour coding, fever charts, and digital 3D visuals).

The temporal dimension of the analysis data, in many cases, poses increased difficulty to communicate to the users when using conventional representation means. Yan and Jiang (2005) believe that current visualization techniques utilized by the big majority of BPS tools have limited capability in supporting the level of complexity generated by the spatiotemporal characteristic of the simulation. Many researchers have called for an original visualization technique that can represent spatiotemporal data in an effective manner that facilitates the comprehension of the relationships and patterns of the presented 4D building analysis data.

Attia et al. (2009), argued that the successful utilization of energy analysis tools as a decision support system (particularly in the preliminary design stages), required defining the simulation process as a social discipline that comprises human-computer interaction with reasonable level of information processing, while simultaneously providing an opportunity for exploring the design space and investigating its various entities. In this aspect, incorporating design assessment criteria -in terms of sustainability and building performance- within a virtual 3D interactive narrative environment (like a 3D game) could prove quite effective and motivating to students.

**GAMES AND EDUCATION**

Playing games, in recent years, have become a prevailing paradigm and pattern of life for most adolescents. Games have become an extension to youngsters’ lives, to the extent that recent studies show that they spend more time playing video games
than playing outdoors. Prensky (2001) presented the characteristics of the modern learners, labeling them as ‘The Games Generation’. This generation of learners has adopted to the play-centered learning techniques, as they are

“accustomed to the twitch-speed, multitasking, random-access, graphics-first, active, connected, fun, fantasy, and quick payoff world of video games, MTV, and Internet” (pp. 64).

It has thus become eminent to incorporate the “Play” metaphor -within an appropriate game context- (Woodbury et al, 2001), in other aspects of their lives, particularly education. The idea of games being a synonym for fun within an educational context has a clear advantage in the students’ comprehension and their cognitive perception. This concept has been widely applied in recent years in the architectural education community.

Dickey (2006) argued that 3D virtual learning environments have the potential not only to associate a narrative structure for situating and contextualizing learning, but also to provide an enhanced sense of spatial reasoning, which go far beyond linear analysis. Representing the geometric space and contextual entities in a 3D environment, and perceiving these elements in first-person perspective, enhances the learners’ sense of presence, engagement, and collaboration, and subsequently improve the quality of learning. The interactive narrative nature of the game enables design students to be immersed in its virtual environment as active participants rather than passive observers to examine their own design ideas. This effect will encourage the students to think about their architecture more as a social and spatial experience. It is even noticeable that many 3D and CAAD application packages have accommodated the ‘gaming experience’ quality in design representation and evolved their interfaces to integrate more game-like features.

Hamza and Horne (2007) promoted the integration of the concepts of ‘Design’, ‘Visualise’ and ‘Simulate’ within an interactive virtual context. They explained that design students are more motivated, and show greater interest in assessing their design models on a performance basis virtually. Visualisation of geometric and non geometric aspects of their design simultaneously is of greater interest, helping them to synthesize number of features of their project (aesthetics, low-energy consumption, geometric masses and relations, etc.) into a whole single integrated model, that has the capacity to push students to a higher ground of understanding. This integrating approach is believed to be of great potential, particularly with regards to the motivational problem discussed earlier.

THE PROPOSED ETUTOR GAME

It is understandable that the students’ initial design outcomes will require considerable enhancements and iterations, just to reach acceptable performance measures and attain reasonable building’s comfort targets. Reaching interior comfort temperatures can be achieved either through harvesting passively (through addressing aspects like solar gains, insulation grades, thermals mass, etc), or through actively enforcing interior temperatures using HVAC systems for example. Since the passive treatment of the building requires certain qualities that students don’t normally possess, the merit envisioned in the proposed tool is not only to investigate data and highlight problems, but also to walk users through the process, and present possible problems’ causalities and routes for resolving them. In this sense, the tool can work as an effective learning context.

The design of a successful course that effectively fulfils the desired learning outcomes, according to Biggs (1999), should incorporate reflective analysis that manifest a ‘Deep Learning’ approach. It can be argued that addressing sustainability and energy efficiency in a design in terms of a technical report in a stand-alone module can only satisfy a ‘Surface’ level of learning. Based on this theory, integrating design, visualization, and simulation in the same module (on the same project) could instigate a deeper level of learning, and have greater effect on
the students’ level of comprehension, skills acquisition, and achievement of the desired objectives. The proposed game attempts to fulfill this through ‘tutoring’ the students with a walkthrough into their ideas, strategies, and design concepts and decisions. The tutoring implemented in the proposed tool is adopting a discussion-based scenario, through interrogation and Q&A routines involving the students. The questions asked seek to form a knowledge base for the proposed design and the strategies the students have implemented, aiding the system to perform a more profound analysis and present the user with effective feedback and useful guidelines. Tutoring the students in this manner is believed to provide them with a chance to critically evaluate and analytically reflect on their work and decisions made, and present them with feedback that pours into the iterative design process.

**MAS and DM**

An agent-based approach has been deemed appropriate for the system development and implementation of the features in this tool. A MAS, according to Wooldridge and Jennings (1995), can be defined as an autonomous entity that is comprised of multiple assorted components (agents), that have the capacity to communicate and interact with each other and with the surrounding environment, aiming to achieve both agent-specific and generic system objectives. An agent can be viewed as a single, self-contained unit that can simultaneously execute a string of commands to achieve a task or maintain a specified state, based on the defined scope of capabilities. The nature and aptitude of MASs can match the intricate nature of the BPS outputs, in terms of data analysis and pattern definition, as well as data representation. In support of this statement, Lesser (1999) argued that computational environments where MAS implementation is appropriate, typically “have a naturally spatial, functional, or temporal decomposition of knowledge and expertise among agents” (pp.3).

In this aspect, computational environments with high degree of intricacy, in terms of processing and/or information scope (like a BPS simulated virtual environment), could benefit from being structured as MAS. The benefit of implementing multiple agents rather than a single omniscient agent in such environments is the opportunity to simplify complex objectives and break down tasks -that could be rather problematical- to smaller supplementary tasks. It is also arguable that in terms of system development, management, and maintenance, a MAS offers a much simpler approach, due to the ‘modular’ nature that is produced from dividing the program into multiple functionally specific modular components (Sycara, 1998). The wealth and magnitude of data obtained from BPS calculations (and other resources) can be overwhelming for design students, particularly if the simulation covers prolonged periods (like annual simulation). For the agents to deal with the available analysis data, they need to adopt a powerful technique that facilitates the interpretation and correlation of information, and extraction of knowledge in its abstract format (Han and Kamber, 2001). Data mining techniques are coupled with the implemented MAS for this purpose. DM process performs sifting, identification, examination, and extraction through employing sophisticated analysis mechanisms (as discussed later) to highlight relevant patterns and relationships in the raw datasets.

**System Architecture**

The proposed tool is built within a game engine that works in conjunction with a BPS application. Ecotect has been chosen as an appropriate BPS application to be used in this context. The simplified nature and interface of Ecotect is considered very effective for design students, as well as being suitable to use in the conceptual stages of design. C4 Engine has been deemed suitable to accommodate the tool’s architecture (Figure 1).

The process starts by building the design model and using it in Ecotect. The simulation process is run in this case using customized automatically
generated LUA script (the scripting language used with Ecotect) which automates the data generation and exportation process (addressing the complexity problem defined earlier). The script is generated from the game engine according to the users' specified requirements and settings. The design CAD model, the generated simulation data, along with data retrieved from various resources (including the model, Psychrometric chart, sun-path diagram) are imported in the game engine and stored in a ‘Data Warehouse’. A Data Warehouse is a local data repository that acts as a centralised point of reference where the run-time queries always refer to. It is where noise-free heterogeneous data (extracted from multiple resources) is collected and stored. The data stored is then processed by the MAS, which employs three types:

Retrieving Agent (Retriever): All the run-time automated and user-defined queries are passed to this agent. It is responsible for refining the questions or information inquiry, and gathering relevant contextual information that could help in further specification of the required information (like current thermal zone, and current data and time). The refined query is passed to data warehouse and relevant data is consequently retrieved and passed to the analysis agent for further processing.

Analysis Agent (Analyzer): When relevant data is passed to the analysis agent, it starts the process of knowledge discovery (Han and Kamber, 2001). The agent uses analysis mechanisms and DM techniques to extract the required information and pass it to the reporting agent. The analysis agent only relies on ‘Descriptive DM’ (Dunham, 2003), which is solely concerned about defining existing relationships and describing patterns in subsets of the available data (for example, defining the periods where temperature is out of comfort range in the current zone). The techniques used in the mining process include

Figure 1
The proposed tool’s system architecture
‘Summarization’, ‘Association Analysis’, and ‘Decision Trees’. These techniques examine data against particular standards and climate equations (Rules), to refine the data and generate the required information.

Reporting Agent (Reporter): It is the only embodied agent, which means that it physically exists within the virtual game world and communicates with the players. It receives filtered extracted knowledge from the analysis agent, and presents them to the users when required (requested reports) or when deemed relevant (instant briefs). The reporting agent is responsible for creating the dialogue with the users interrogating them for information, and presenting feedback and design guidelines. In this aspect the reporting agent is not only implemented as a structural element in the system architecture, but also the narrator/tutor of the building story, and the users’ companion throughout their journey within the building (Tallyn et al, 2005). The reporter gathers information from the users and passes them back to the retrieving agent to either store in the data warehouse, or to process and retrieve relevant data. The iteration process is completed by the feedback and guidelines presented to the users, which form further design decisions to the CAD model, and thus the process can be repeated.

**Features and Functionalities**

On starting the game, students are given a chance to define some custom settings that could affect the game, including the current date and time, number of building occupants, hours of occupancy, and the type of activities performed. The virtual experience starts outside the proposed building, presenting current outdoors temperature and sun location (Figure 2). Once entering the building (which is split into separate thermal zones), the reporter generates a run-time zone brief, presenting current zone temperature and a summarized report about its state. This brief covers brief assessment of the current daylight and thermal affairs.

The users can generate more detailed daily, monthly and yearly reports for the current zone. This reports mine information to highlight the key aspects of the zone’s performance (using ‘Summarization’ DM techniques) and define any noted problems with their possible causalities (using ‘association Analysis’ DM technique) (Figure 2). The generated reports are presented in a relatively simple and user-friendly manner, to avoid any confusion and uncertainty that could affect any judgment or decisions.

The tool engages the users in QA interrogation routines -mimicking that of a real tutorial- (Figure 3). The questions are elected and presented to the user with relevance to the current state of the virtual experience and the information gathered earlier. The questions may either require missing information, or ask the users’ opinion regarding the suitability of a strategy. For example, asking questions about the ventilation strategies, effective area of opening,
solar gain strategies, etc. This QA manner insures an engaging game narrative constituting questioning and feedback, which in general enriches the value of the users’ virtual learning experience. The tutoring virtual experience is finalized by presenting a set of zone-specific design guidelines (Figure 3). The defined guidelines are based on number of resources including Watson (1983) and Loftness (1970). These guidelines address directly the current performance and problems noted, and offer help to improve the design and thus eliminate (as much as possible) the problems. Interrogation routines and guidelines are generated using the ‘Decision Tree’ DM technique.

**Users Testing and Evaluation**

The proposed tool has been presented to number of potential users and stakeholders to assess the concept and its effectiveness and suitability within the desired domain. The stakeholders were categorized into inexperienced (undergraduate students), users with basic experience (researchers), and experts (instructors). Users were involved in three waves of evaluation through user trials, questionnaires, and structured interviews. The first two waves focused on building the requirement specification set, based on the identifying the difficulties encountered with integrating environmental variables, and also based on features that stakeholders deem imperative to improve the integration.

Generally, the tool was well received and appreciated by the users, particularly the students. They noted that the representation of their design concept in an interactive 3D medium like a game environment is of predominant interest to them. Students also liked the automation of the simulation process using the automatically generated LUA script, noting that it could save a lot of time and effort trying to figure out what to simulate and how. Instructors were also interested in the interrogation routines and zone-specific guidelines presented. Users in general liked the fact that this tool is architect-oriented, addressing the needs of the designers in their own domain, without having to deal with loads of graphs and numerical quantitative calculations.

There were, however, some concerns raised with this concept. Some students noted that this method adds more workload to them, as they are supposed to learn and use a new interface (the game’s world editor). Some others mentioned that it is still daunting to have to build and model in Ecotect and specify initial required parameters before automating and running the simulation. They mentioned that some default settings and parameters could be implemented to speed the process, particularly in the early design stages. Instructors noted that it is important to add links to more detailed information within the game itself for every environmental term encountered.

![Figure 3](image-url)

**First screen: Interrogation routines. Second Screen: Zone-specific design guidelines**
CONCLUDING REMARKS
This paper presented a method that utilizes games (as a virtual learning medium and a technology), coupled with MAS and DM techniques to assist students and untrained professionals in interpreting, analyzing, correlating, and visualizing environmental and building analysis data thus facilitating the comprehension of implication of their strategies on a building in different design stages. The related tool has been developed and presented to potential users and is currently undergoing further testing and evaluation. The tool is generally perceived to be useful and has great potential to assist the design students, as it communicates and present feedback in a qualitative rather than quantitative format thus could be a sophisticated teaching and knowledge-based tool.

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