Sustainable carbon neutral building design: new simulation tools for teaching green buildings

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Abstract

The Building Industry is one of the major consumers of energy. In the United States buildings use 48% of the total energy consumed, significantly impacting national energy demand and contributing to global warming. The vast majority of architectural practice in the U.S. leads to construction of buildings with little concern to sustainability contributing to environmental degradation. However, as the environmental impact of buildings become increasingly recognized, the role of architects and the initial decision making process which determines the resource use and life-cycle of materials, systems, and construction processes, becomes more critical.

In order to advance sustainable development and make green building construction the standard rather than the anomaly, the education of the architects must be reconsidered. The traditional American architectural curriculum that is based on a schism between "design" and "technology" is inherently in conflict with the principal of sustainability.

Recent research in building design indicates that the most resource efficient, best performing, and environmentally sustainable buildings are designed utilizing "integrated practice," in which the various disciplines involved in building design work together at the conception of the project to improve overall building performance, reduce GHG's, and lower the costs for operation and maintenance of buildings.

Although large-scale reform of architectural curricula is a complex, ongoing, and difficult debate, producing teaching tools that can simulate integrated design can impact and promote a better understanding of sustainable practice in architecture.

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The proposed paper will present the progress of a multi-disciplinary team of faculty who are collectively working on the completion, implementation and evaluation of a simulation software package in an interactive game format. The project teaches the concepts of "integrated design" through immersing students in a virtual world that imitates the complexity of the real world of decision-making and material choices in design. The project accomplishes this by harnessing the capabilities of simulation and dynamic modelling programs as well as powerful game engines while creating compelling and rewarding reasons for student's engagement in the learning process. The project is funded by the US Department of Education for the period of 2007-2011.
Keywords: educational tools, teaching sustainable design, augmented learning, instructional technology, green building design.

1 Introduction

The Building Industry is one of the major world-wide consumers of energy. In the United States buildings use 48% of the total energy consumed significantly impacting national energy demand and contributing to global warming [1]. Seventy-seven percent of all the electricity produced in the U.S. is used just to operate buildings. Globally, these percentages are even greater [2]. Building and construction activities consume three billion tons of raw materials each year [3]. Materials utilized in buildings tend to have a high-embodied energy, high levels of toxins and pollutants at the end of production, as well as higher levels of emissions [4].

As the environmental impact of buildings become increasingly recognized, the role of building designers and the initial decision making process which determines materials, systems, and construction processes, becomes more critical. Thus, an informed design process merging environmentally responsible practices with advanced technologies can significantly reduce the adverse impact of buildings on the environment.

A critical component of an informed design process is a clear understanding of building systems operation, interaction, and the synergetic benefits realized through their proper selection. A consideration of suitable building systems, gauging their interaction, and proposing well integrated systems can lead to producing efficient models of sustainable buildings with minimal impact on the environment [5].

The project presented in this paper reports on the progress of a multi-disciplinary team of faculty who are collectively working on the completion, implementation and evaluation of a simulation software package in an interactive format. The project is funded by the US Department of Education for the period of 2007-2011. The project teaches the concepts of "integrated design" through immersing students in a virtual world that imitates the complexity of the real world of decision-making and material choices in design. The project aims to accomplish this by harnessing the capabilities of simulation and dynamic modeling programs to create interactive and compelling reasons for student engagement and learning.

2 Project approach

The project is developed based on a few pedagogical principles: First, an interactive educational format is critical for engaging students in the process of learning. Students should be empowered to learn at the level of their individual ability while receiving support for their activities. Second, any meaningful attempt to advance technology education in the architectural curriculum cannot be pursued in isolation from the design process. Finally, understanding systems integration is a critical component of designing sustainable, carbon neural, and resource efficient buildings.

The educational content of the project is composed of two interdependent modules of Simulation Environment and [eco]Learning Interface. The following section is a detailed explanation each of these components.

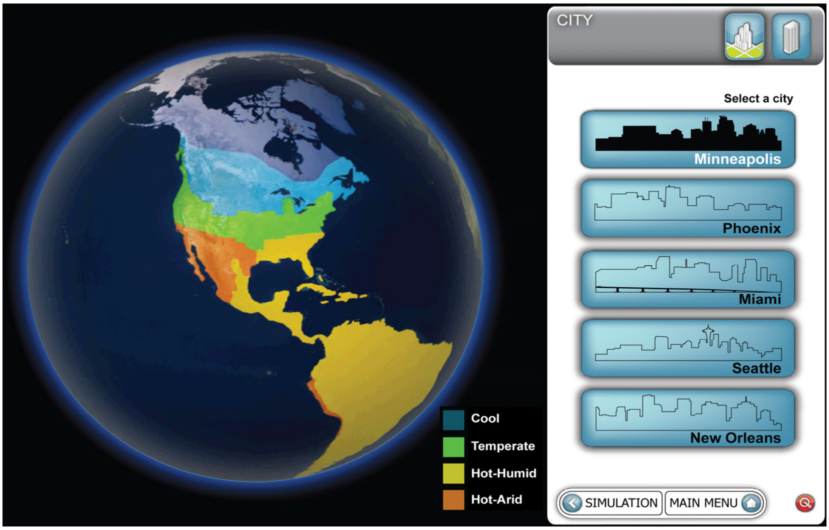

Figure 1: The Simulation Environment Interface.

2.1 Simulation environment

The simulation environment is the core component of the project developed to engage students in a series of scenario-driven building design projects that make a case for sustainable design and construction. These scenarios take on a variety of ecologic and economical issues such as squandering natural resources, fuel and energy cost, and climate change. They take place in a variety of building sites and contexts allowing the students to select the venue for their learning. In each case the scenario lays out a challenge for composing a building through balancing the demanding requirements of site and climate, form and function, energy and sustainability, and building systems. Each scenario is introduced with a movie explaining the details of the required activity. Once the student has selected a mandate he/she will move to the user interface and start to assemble a building.

The simulation environment provides access to a library of building tools that contains a wide range of preconfigured building components to be used to assemble a building. Navigating through these choices enables the student to investigate and learn about each building component and their relevant properties. Each building component is tagged with a series of metrics and attributes which are imported to the interface when the component is selected. All selected choices are all stored in the library of tools ready for assembling the building and running the analysis function. During the assembly, the student can organize, move, group and edit the selected components. Specific components of the Simulation Environment are the following:

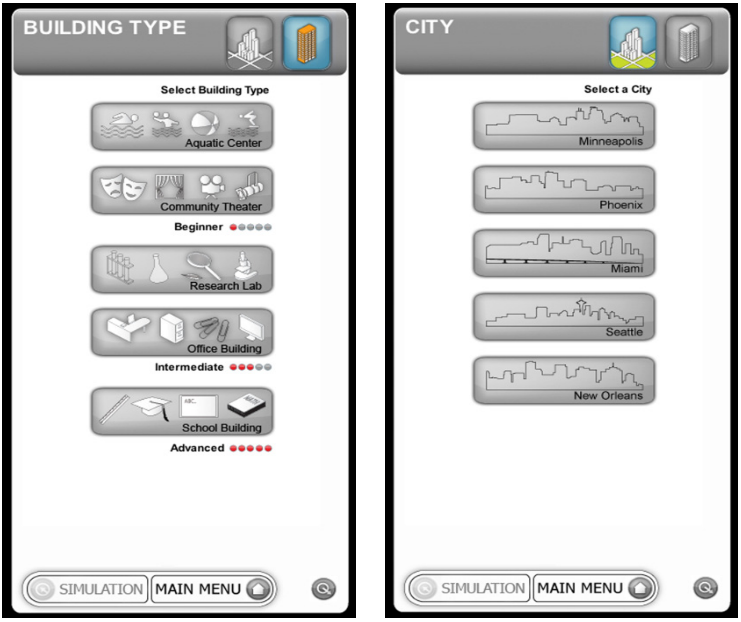

Figure 2: Menu for scenario selection.

2.1.1 Scenarios

Scenarios will provide a choice of architectural programs such as Community Center, Research Laboratory, School Building, etc. Once a choice is made the next menu will allow the student to select one of the four climatic conditions of hot and arid, hot and humid, temperate, and cool as the context for their building assembly. Once the initial selections are made, a brief movie will launch a scenario with a narrated story and three dimensional graphics introducing the entire project. The movie will include full textual and visual information of the site, the surrounding environment, topography, climatic conditions, and a detailed square footage requirement of the building program. Once the user is given the mandate, the building assembly begins.

2.1.2 Library of building blocks

Library of Building Blocks includes a number of pre-arranged computer generated models of various building components including floor templates and program elements that are used to make a building assembly. Floor templates are the initial step for creating floor plans. They indicate the shape and the exterior boundaries of the floor area, and once a selection is made the floor plan can be laid out. Program elements compose the functional components of a building such as, rooms, public spaces, dining areas, stairs, elevators and etc. The student can investigate each arrangement by placing it on the main window and examining how a particular arrangement responds to the site and the climate conditions. For example, the student can compose a horizontal arrangement of the building mass and place it in various orientations on the site to examine its energy efficiency in relation to solar orientation. In a hot and humid climate, a horizontal arrangement of open spaces such as offices which are extended in the east-west direction will provide cross ventilation of air from a southern summer breeze, reducing the need for mechanical ventilation. This arrangement will also maximize the utilization of natural day light. The feedback from this simulation environment will allow the student to investigate these and many other interactions of the building volume in response to the climate and the site. Understanding these complex interactions are a critical component of sustainable design. These interactions will be analyzed with simulation algorithms and exhibited for view in both numerical and graphical format.

2.1.3 Building envelopes

Library of Building Envelope Elements is a number of detailed computer generated models of building envelope systems such as walls, roofs, floors and windows. Each element is modelled as modules of 8ft x 12ft panels and carries properties of every material used in its composition. For example, a cavity wall is modelled with brick at the exterior surface a layer of air; rigid insulation, flashing, a layer of vapour barrier, concrete masonry, and painted gypsum board in its interior surface. Each material's physical properties or attributes such as specific weight, thermal resistance, embodied energy, and percentage of recycled materials is embedded within the choice and is imported for future performance analysis. The student could use the imported values from the preconfigured data set or enter another value to modify the design conditions. The attributes of each component will be added and editable for analysis once the building is completed.

2.1.4 Building systems

Library of Building Systems Components includes computer-generated models of building systems such as Structural Systems, Heating Cooling and Ventilation (HVAC), Alternative Energy Systems, and Lighting Systems. The student can browse the library of systems and investigate a variety of choices. For example, the HVAC Systems selection allows the student to study a series of systems such as Fan Coil Units, Variable Air Volume Units, Water Source Heat Pumps, and Packaged Terminal Air Conditioners.

Figure 3: Screen shot showing an assembled building.

2.1.5 Analysis

Once a building is completed the student can run a few different types of analysis. The main analysis is the solar radiation simulation. This is designed to provide a better understanding of performance of the building fenestration and envelope systems. The results of the analysis provide the students with an understanding of how the location, orientation, window selection, shading, lighting and exposure will affect building heat and cooling load. The other analysis includes a summary of embodied energy, embodied water, percentage of recycled material, and an estimate of materials cost used in assembling the building. This information will allow the student to understand the impact of their choices and tradeoffs in cost versus environment.

2.2 [eco]Learning interface

The second component of the project is the [eco]Learning Interface which contains the pedagogical component of the project. It is an interactive learning tool developed to advance the education of climate responsive and ecologically sustainable buildings design and construction. [eco]Learning Interface is composed of lessons in six content areas including building form, building envelopes, climate control systems, renewable energy, natural and artificial lighting, and landscape

Each of these content areas is subdivided into learning modules that introduce the subject matter and investigate the related sustainability issues and strategies. Eco[Learning] interface harnesses the capabilities of advanced media to help users to visualize and engage with concepts that may otherwise be too ambiguous or difficult to comprehend in the traditional book format. The interface utilizes hyperlinked text, interactive diagrams, animations, analytical data and graph exhibits to provide an augmented learning environment that is accessible for users with a various learning styles and needs.

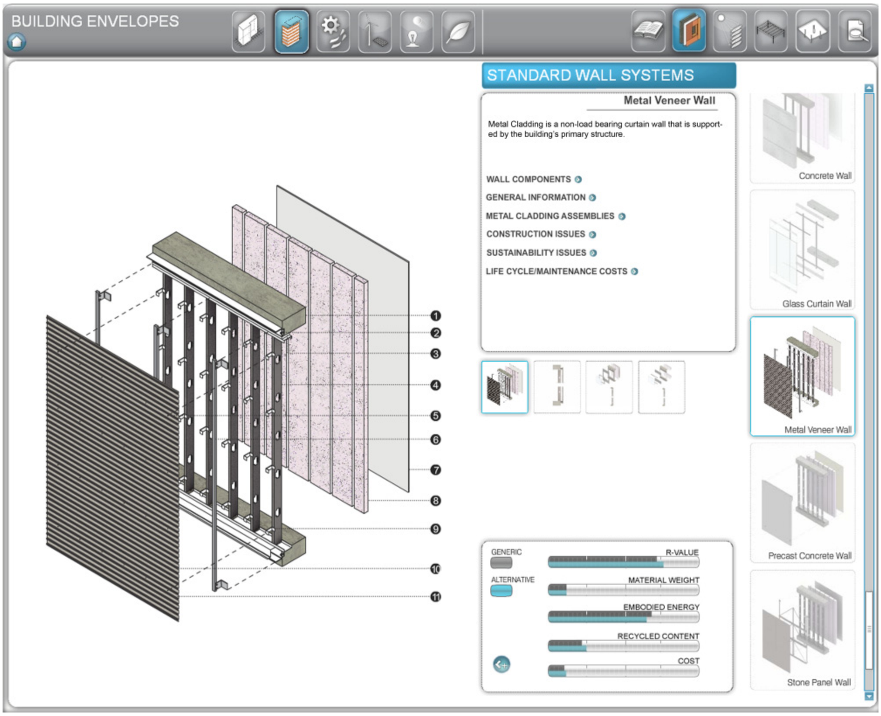

Figure 4: Screen shot showing [eco]learning interface.

This interface can be accessed from the Simulation Environment or used as an independent tool for teaching building sustainability concepts and principles. When accessed from the simulation environment, the interface provides lessons and information to help students make educated selection and compare alternatives with adequate knowledge.

The project is in its last year of funding. Once completed, it will be formally tested and evaluated, and the results will be disseminated to schools of Architecture across the nation.

3 Closing remarks

Given the size of the built environment as energy and materials consuming sector, raising students' awareness and technological competency to design efficient and sustainable and carbon neutral buildings can have a significant impact on the architectural profession as well as the national energy consumption. Though large-scale reform of architectural curricula is a complex, ongoing, and difficult debate, changing the pedagogy and delivery system of the educational content is the critical next step. The current advances in our technological capacity and the informational technology have created new opportunities to reform the traditional classroom. These technologies can help to change the role of the student from a passive observer to an active participant. The project discussed here is an example of producing teaching tools that harness digital capabilities of advanced graphic media and simulation applications for improving the sustainability education.

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