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Interactive Teaching through Simulation Environments

:abstract

Spurring new and innovative building design will be critical to the urban energy and economic future of the nation. The operation of completed buildings account for 48% of the nation's annual greenhouse gas emissions, and 76% of all electricity generated by U.S. power plants goes to supply the building sector. Therefore developing and applying new and innovative sustainable building design will have a measurable impact on the environment.

Recent studies show sustainable building design is closely linked to system integration, where various components of a building work in confluence to produce synergetic benefits. As a result, a critical component of sustainable design involves a clear understanding of building systems operation, interaction, and the selection parameters. 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.

The following paper outlines the progress on a project entitled "Building Literacy: the Integration of Building Technology and Design in Architectural Education." The project develops a digital tool for teaching/learning architectural technology from an integrated systems perspective. The project attempts to immerse students in a simulated environment that is based on the real life practice of architecture. The project accomplishes this by harnessing the capabilities of simulation and dynamic modeling programs, as well as the state of art graphic media, to create compelling and rewarding reasons for students' engagement in the learning process.

The project involves a multidisciplinary team of faculty from Florida International University, University at Buffalo the State University of New York, and Iowa State University and is funded by the US Department of Education for the period of 2007-2011.

1 Introduction

A significant component of informed design process is a clear understanding of the building systems operation, their complex interaction, and the synergetic benefits realized through proper selection. Unfortunately the traditional architectural curriculum is based on a schism between "design" and "technology" that is inherently in conflict with the principle of integration. In most architecture programs the building technology curriculum is rarely integrated into the broader architecture curriculum and is often taught outside the studio (Cavanagh and Allen 2004). When studio and building technology courses are not integrated, valuable opportunities to reinforce and apply innovative concepts are squandered, and learning the pivotal importance of technology as means to drive innovative and creative design is completely missed *(Addington 2003)*.

In addition, the technology lecture courses in many architecture programs have the same structure as the conventional engineering courses. While the architectural systems are complex and interactive, in lecture courses, they are normally introduced as well defined problems with clear boundaries and a limited number of solutions. Although students may master the specific domain knowledge, their ability to apply this as a problem solving skill in the design process is questionable. Studies have shown that knowledge acquired from learning how to resolve well defined problems is not directly applicable to solving ill-structured problems of the real world *(Cho and Jonassen 2002)*. To address the increasing demand for complex reasoning, integrated learning is paramount to the future success of the students. Thus, learning is no longer primarily about reaching specific learning objectives, but about the ability to flexibly apply what has been learned in new problem situations *(Cho and Jonassen 2002)*.

There is also another shortcoming with the lecture format which exacerbates the problem. Recent research indicates the passive lecture format or "instructional paradigm," where the teacher lectures and the students listen, may not be the most effective setting for learning. Numerous educational researchers have focused on developing student centered learning environments that are based on self directed learning systems. These learning environments provide educational materials that are highly interactive task oriented, and enable students to control the pace of their own learning *(Rachke 2003)*.

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 and transform the role of the faculty from a lecturer to a consultant—similar to that of the studio environment.

Computer Modeling and Simulation Environments

The recent advances in computing technology and simulation algorithms have enabled architects and the other design professionals to collaborate, visualize, foresee, and modify building performance with relatively high accuracy. Computer simulation and parametric modeling are increasingly used to analyze complex systems to achieve streamlined structures, reduce dependence on mechanical systems, and produce more effective construction. Building Information Modeling (BIM) technologies have been widely adopted because they offer many benefits for general building design. They provide for collaboration, systems integration, and better coordinated and consistent construction documents while minimizing errors and omissions.

Many of these technologies are developed to improve architecture and engineering practice in response to the needs and demands of practitioners. Although they are widely used in architecture curriculum for their analysis and modeling capabilities, they do not provide specific domain knowledge. Students are expected to know about building systems and architectural technology prior to full engagement with the programs. This is natural, as these simulation environments are not designed to meet the students' demands and lack pedagogical methodology and content. The project outlined here, aims to address this issue by providing a teaching tool that utilizes the computer simulation capabilities for delivering the content of architectural technology courses.

2 Project Description

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.

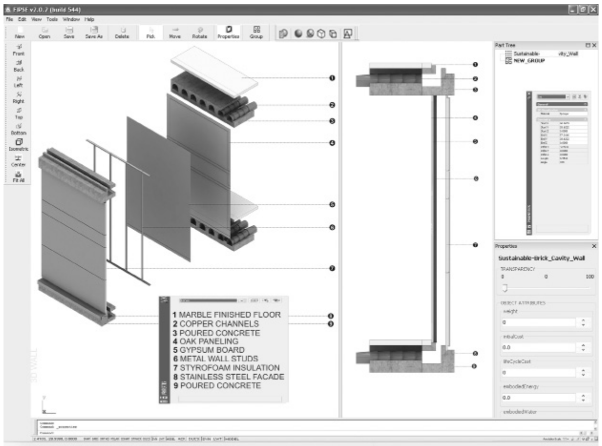

Figure 1. Project interface main and secondary window.

Typical Walls	Material Volume in CF	Material Weight lb	R-Value	Initial Cost PSF	Embodied Energy (btu)	Recycled Content (weighted avg.)	Total Embodied Water (gal)
Stone Panel Wall (8'x12')							
Stone (Imported)	9.9134	1564.33	0.08	$67.50	4,575,678.47	0.00%	1274.46
Compressable Filler w/ Sealant	0.0694	8.33	N/A	$0.59	394,105.94	0.00%	109.77
Weatherproof Membrane (polystyrene)	0.48	0.50	N/A	$0.20	25,280.64	0.00%	7.04
1/2" Gypsum Wallboard (both sides)	8	336.00	0.84	$1.92	1,139,040.00	2.15%	317.26
Steel Frame (Wall Studs/BOF) $0.295/LF (93LF)	0.3455	168.95	N/A	$3.60	2,485,247.15	0.49%	692.22
Fiber Glass Insulation	40.219	48.26	16.05	$0.74	579,150.72	0.49%	161.31
Steel Frame (Stone Studs/BOF) (75LF)	0.6279	307.04	N/A	$23.05	4,516,604.00	3.91%	1258.01
Extruded Insulation (XPS)	24	48.00	15.00	$1.32	2,419,200.00	0.00%	673.82
Per Square Foot of Wall		**25.85**		**$98.91**	**168,065.70**		**46.81**
Total Wall		**2481.42**	**31.97**	**$9,495.59**	**16,134,306.92**	**7.03%**	**4493.89**

Sustainable Walls	Material Volume in CF	Total Material Weight lb	Total R-Value	Initial Cost PSF	Total Embodied Energy (btu)	Total Recycled Content (weighted avg.)	Total Embodied Water (gal)
Stone Panel Wall (8'x12')							
Stone (Domestic)	9.9134	1564.33	0.08	$67.50	531,873.74	0.00%	148.14
Compressable Filler w/ Sealant	0.0694	8.33	N/A	$0.59	394,105.94	0.00%	109.77
Weatherproof Membrane (polystyrene)	0.48	0.50	N/A	$0.20	25,280.64	0.00%	7.04
1/2" Gypsum Wallboard (both sides)	8	336.00	0.84	$1.92	1,139,040.00	0.00%	317.26
Steel Frame (Wall Studs/BOF)	0.3455	168.95	N/A	$3.60	2,485,247.15	2.15%	692.22
Mineral Wool Insulation	40.219	48.26	16.05	$0.56	313,706.64	1.46%	87.38
Steel Frame (Stone Studs/BOF)	0.6279	307.04	N/A	$23.05	4,516,604.00	3.91%	1258.01
Extruded Insulation (Polyisocyanurate)	24	48.00	21.60	$2.37	1,488,000.00	0.17%	414.45
Per Square Foot of Wall		**25.85**		**$99.79**	**113477.69**		**31.6069**
Total Wall		**2481.42**	**38.57**	**$9,579.74**	**10893858.11**	**7.69%**	**3034.26**

Figure 2. Table of attributes tagged with each imported element.

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 and resource efficient buildings.

The core educational content of the project is composed of two interdependent modules of 1) the Simulation Environment and 2) the Learning Interface.

2.1 Project Simulation Environment

The project revolves around the student playing the role of an architect and developing design strategies which are similar to the experience of a real-world practicing architect. The Simulation Environment provides two options of Preset Scenarios and User Defined Scenarios.

The Preset Scenarios are developed to engage students in a series of building design projects that make a case for sustainable design and construction. Each scenario lays out a challenge for composing a building through balancing the demanding requirements of site and climate, form and function, and energy and sustainability.

In the Preset Scenarios, the student begins a new project by selecting a level of difficulty and a specific building type in a particular climatic zone. The Preset Scenarios provide the user with a choice of a number of different cities and sites in the four climatic zones of cool, temperate, hot and humid, and hot and arid. The building types are grouped based on their level of complexity ranging from beginner, to intermediate, to advanced. Once the site and building type are both selected, the environment will launch the required information for the design and assembly of the building. The information includes full textual content, three dimensional graphics, animations, and audio narrations providing information on the site and the surrounding environment, topography, climatic conditions, building function, and detailed square footage requirements. Each selection will include an animation of the sequence and process of an exemplary assembly which leads to an efficient design. Once, the user is given the mandate he/she will move to the User Interface and the building assembly begins.

The User Defined Scenarios option allows students to define their own design parameters, including building site, program, size, and climatic conditions. To advance with this option, the user will import a three dimensional site model in a particular file format containing climatic data for a specific geographical location. To assemble the building, the students can use preconfigured elements from the environment or import their own building elements with a series of required attributes.

The following paragraphs describe the details of the Simulation Environment and some of its features with respect to its pedagogical aspect.

1) Navigation

The Simulation Environment includes a main and a secondary window. The assembly process will occur within the main graphical window. The secondary window contains the core pedagogical content of the software by providing access to the Learning Interface (Figure1). Each time a building element is selected the user can access lessons that contain pertinent information, specifications, and analytical data, cost, and graph exhibits (see section 2.2 for details). This allows the student to study each selection and evaluate the advantage and disadvantage of each choice.

2) Library of Building Components

The Library of Building Components contains a wide range of pre-configured building blocks including Floor Templates, Program Elements, and Building Envelopes. The Floor Templates include a number of floor layouts available for each architectural program. They contain the geometry and the perimeter of each floor and the circulation space. Selecting a Floor Template is the initial activity for assembling a building. Prior to finalizing a selection the students can investigate their choice through the secondary window by activating interactive text, graphics, and animations that highlight lessons for the specific floor layout. Once finalized, the student will move to the next stage and import the Program Elements. These consist of a number of pre-arranged three dimensional building blocks including rooms, public spaces, dining areas,etc. The program elements include data regarding square footage, material weight, area, embodied energy, embodied water, percentage of recycled content, and initial cost per square foot (Figure 2). The software keeps a tally of these attributes providing a base for cost/benefit analysis with respect to the environmental impact and the entire building cost.

The Building Envelope elements are a number of detailed computer generated models of building envelope systems such as walls, floors, roofs, and windows. Each element is modeled as 8ft x 12ft modules and carry properties of every material used in its composition. For example, a cavity wall is modeled with brick at the exterior surface, a layer of air, rigid insulation, flashing, a layer of vapor barrier, concrete masonry, and painted gypsum board in its interior surface. Each material's physical property such as specific weight, thermal resistance, embodied energy, embodied water, and percentage of recycled materials is embedded within the choice and is imported for the performance analysis.

All modules are composed of two major categories of standard and alternative built elements. For example, the standard façade category provides a choice among the common glass curtain wall, metal veneer wall, precast concrete wall, stone panel wall, and brick curtain wall. For each selection the student will be able to investigate an alternative option with sustainable characteristics.

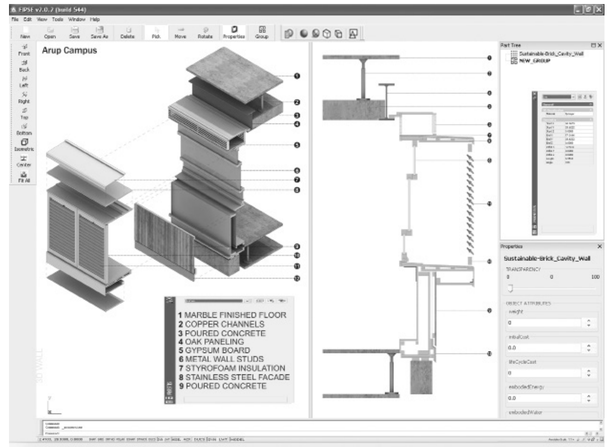

Figure 3. Custom wall based on Arup Campus building envelope.

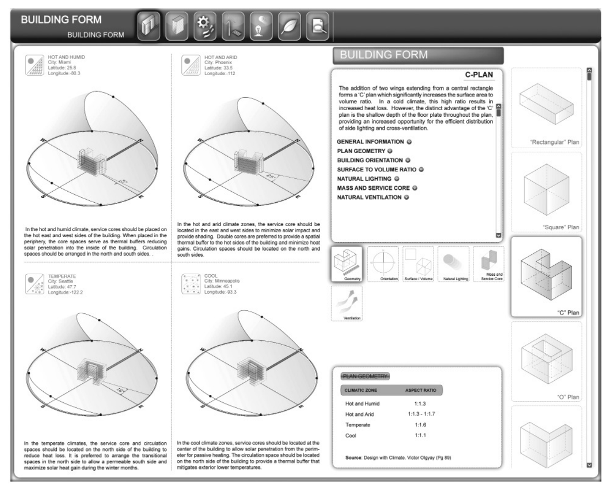

Figure 4. Learning Interface lesson on Building Form.

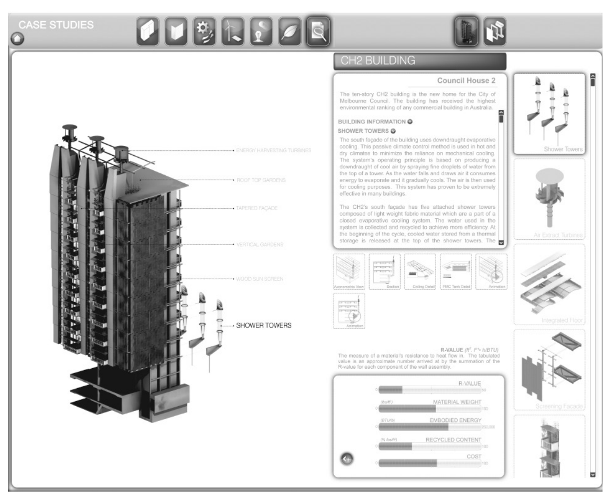

Figure 5. Learning Interface case study on CH2 Building.

The student may also choose one of the custom walls exhibited in the Virtual Case Studies section (Figure 3). These facades have unique features and are modeled from buildings designed by prominent architects. These include many options on double skin facades that are an integral part of the building's overall energy efficiency system.

3) Building Performance Simulation

Once the building assembly is completed, the student can run the Building Performance Simulation which includes a few different types of analysis. The main analysis is the solar radiation simulation. This is designed to provide a better understanding of the performance of the building fenestration and envelope systems. The results of the analysis are quantifiable measures for evaluating sustainable choices and strategies employed in the assembly process. They provide the students with an understanding of how the location, orientation, window selection, shading, lighting and exposure will affect building heat and cooling loads. The calculations follow the process described in the *2005 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook*.

The other analysis include a summary of the total embodied energy, embodied water, percentage of recycled material, and a cost estimate for the materials that were used in the building assembly. This information will allow the students to understand the impact of their choices and trade-offs in cost versus environment.

2.2 Learning Interface

The Learning Interface serves to deliver the educational content of the software. It includes many lessons, case studies, analytical data and graph exhibits on sustainable building construction. The Learning Interface is a vehicle for learning on demand. It enables the student to look up a subject or term and get linked to individual instructional lessons. It can be accessed before and during the assembly process. The Learning Interface incorporates lessons on building form, building envelopes, climate control, renewable energy systems, lighting and landscape (Figure 4). The interface also includes a section of Virtual Case Studies. These examine principles of sustainable building design through the study of recently completed works of architecture that exemplify effective building integrated systems. The precedents include graphic and textual information describing the environmental strategies. In each case study, the building is broken down into the main sustainable features (Figure 5). The student can examine these systems in detail and investigate how they affect the building performance.

3 Project Evaluation

A significant component of the project is an evaluation plan developed to test its effectiveness. The Evaluation Plan has three objectives: 1) to determine the project effectiveness in improving students' understanding of building technology and systems integration principles; 2) to verify if the knowledge and skills gained in architectural technology are transferred and applied into student's design work; 3) to evaluate if the project improves student awareness of the sustainability issues in design.

The evaluation plan has a formative and a summative component. The formative component has resulted in collecting responses from the project team, faculty, and students through a series of survey questions on the beta version of the project. The summative component of the evaluations will be implemented after completion of the project by simultaneous testing between parallel institutions serving as experimental and control groups. All the collected data will be analyzed using suitable statistical methods.

4 Conclusion

Since the built environment is a major energy and materials consuming sector, raising architectural capacity to design more efficient and sustainable buildings can have a significant impact on the environment. The project discussed here seeks to produce a tool for teaching building systems integration by harnessing the capabilities of advanced graphic media. Such a tool allows the students to use creative expression while participating in solving complex problems. Although the project has the capability of simulation and performing limited analysis of the entire building assembly, its main functionality relies on delivering lessons based on demand. Every component in this environment can be investigated in terms of their properties prior to its application.

The project will have a few significant limitations in its first release. One limitation is that all the preconfigured elements used for the building assembly are orthogonal and the program does not support complex building forms. Another limitation is that although buildings can be assembled quickly, they can only be stacked with repeated modules and the project has no structural analysis capacity in the environment. The project team hopes to acquire further resources for future releases that overcome these shortcomings.

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