Using Simulation Applications for Sustainable Design and Construction

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Abstract–

This paper briefly illustrates the application of Building Energy Consumption Simulation (BECS) for sustainable construction education. The curricula of building-related majors have not greatly taken advantage of simulated environments as supplementary tools besides traditional methods. The main purpose of the research project was to determine how a simulation application can be used in a construction curriculum. In order to apply energy consumption optimization in a construction project, there are various suggestions and guidelines that should be carefully incorporated in design and construction phases. BECS is a simulation application that navigates construction students through a set of pre-defined stages and provides necessary information accordingly. BECS puts students in a role of a designer and requires them first to specify the main properties of the construction project such as location, total area, height, orientation, shape, function, and number of levels; and then, interactively specify the characteristics of a building element or construction method in each stage of simulation. The diversity of students' responses were portrayed by 3D avatars accompanied with related calculations and corresponding criteria. Each stage iterates until design and details are satisfactory. The final result, depicting construction details, is shown at the end based on each students design process in accordance with sustainable construction criteria. This study aimed to investigate the effect of using simulation on participants' perceptions of simulation on learning sustainable construction concepts. BECS was tested by a group of 42 undergraduate students in fall 2015. A quantitative method was used in this research. The data retrieved from a retrospective pre and post-test survey were clustered into three main categories. These categories represent sustainable construction contents provided in BECS. A t test was performed to show any statistical difference between pre and post situations. The results support development of more sustainable construction simulation applications and indicate BECS is an effective tool for sustainable construction education.

Keywords –

Simulation; Sustainable Construction; Education; Building Energy Consumption

1 Introduction

Educational systems have been largely changed by the emergence of the Internet, PCs and laptops. Their capabilities are increasingly developed and this has resulted in the development of programming languages and a variety of software, which enhances the design and development of educational materials [1]. Using these tools for education has improved the quality of education and contributed to lifelong and active learning, learning engagement, and virtual education [2]. It is shown that using simulation applications has improved students' engagement [3]. Computer-mediated education methods include computers as tutors, practice and repetition, the inductive method, play method, computer-managed instruction, and finally computer-assisted simulation [4].In educational systems, using simulation applications is an effective method for training in complex situations [5]. Simulation is a tool for creating real phenomena [6]. In simulation, the situation is made as similar as possible to the real position, so that what is learned can be transferred to the real environment [7]. In fact, most simulators are made based on real life descriptions, although, they have been changed for educational purposes. Simulation, as a training method, includes activities that imitate a real environment and has been designed to illustrate processes, decision-making, and critical thinking by using methods, such as playing role and using tools, such as instructional videos and applications [8].Using simulations has been widely increased, as they provide opportunities for students to apply the knowledge gained in the classroom [9]. Learners should develop the concepts and skills necessary to play roles in the target fields to progress through simulated environment. The simulated teaching model is an effective training technique through real activity and subsequent discussions. It also develops various educational targets, such as development of concepts and skills, cooperation and competition, logical thinking, decision-making, conformity, understanding political, social and economic systems, feeling individual usefulness and satisfaction, and awareness of the consequences [10]. Using simulation in training is an application of cybernetic principles that was simulated in the 18thcentury in the form of games [11]. Project-based learning method, which is often a main element of simulation applications, also has a history dating back more than a century [12], however, the history of modern simulation in training goes back to World War II, when it was used to train pilots [13]. Then, modern simulation applications were used to teach sciences, such as nuclear and military fields and in the past few decades it has been increasingly taken into consideration in medical education [14]. Other fields like construction and project management are incorporating subject-oriented simulation in their curricula [15, 16]. Despite the use of simulation application in various fields, it has not widely used in construction. However, literature review shows that due to changes in construction training, using simulation in the training of construction disciplines is gradually expanding [17]. There are still some challenges in using this method practically in construction programs, so that this approach can be facilitated by detecting challenges and effective planning to solve them. According to [18], “there are a number of technical, curricular, political and practical factors that could emerge may inhibit implementation of a project-based construction curriculum”. In this paper, a brief explanation about the types of simulations is given, and, then, the necessity of using simulation in education of construction and challenges associated with the use of this approach are discussed.

1.1 Simulation Steps

In general simulation model has four steps: justification (preparation), participants training, simulation, and asking questions. During the first step, instructor provides some explanations about simulation and general concepts and explains an overview on the play. This step is an important background for the next steps. In the second step, instructor determines a scenario with introducing rules, roles, methods, scoring methods, and simulation purposes to learners, and organizes the learners in various roles. In the third step, learners participate in the simulation and instructor plays his or her role as an educator or arbiter. Finally, in the fourth step, considering purposes, instructor can ask questions from students to contribute in their reflection about the materials [10].

1.2 Challenges of Using Simulation

Despite many benefits of simulation, this learning method also has disadvantages that have limited its use in training. For instance, faculty members are not very familiar with this approach and the way to use it, educators are needed to train, and also there is a resistance against changing the common educational practice [19]. According to [20] many faculty members have not received any training on the use of simulation, and, therefore, are inexperienced in this field.

2 Background

It has been shown that nearly half of the energy consumed in the world is being wasted in buildings. Other consumers in this regard are industry and transport whose activities are closely associated with buildings and their places. Therefore, energy consumption in buildings should be paid attention [21].Sustainable construction includes a wide range of issues, such as optimal energy consumption in various stages (design, construction, operation, and demolition of building) and the use of building materials that cause less damage to the environment, increase the quality of building, and decrease the negative effect of construction on environment around the building to a minimum level [22].It is hard to understand the behavior of buildings in relation to energy consumption and design low-energy building without using tools that can calculate the energy consumption of buildings before constructing. Energy simulation applications are tools used to calculate the energy consumption of buildings and understand their behavior. Finally, building energy consumption before and after changes can be accurately calculated and compared by modeling the dynamics of energy. In this case, except comparing building energy consumption before and after changes, the energy consumption of building before implementing changes and the strengths and weaknesses in terms of energy can be informed [23].

Currently, there are a few simulation applications that are developed with a specific purpose and target. Except the model which is used for calculations in modeling simulation, which determines the accuracy of calculations and static and dynamic modeling, the capabilities of simulation is different. Therefore, construction experts should equip themselves with modeling tools. BECS is an energy modeling simulation application to simulate buildings in terms of energy. The purpose of this application is that the user can apply the necessary changes (in insulation or materials) to optimize consumption energy in a simulated environment, and observe the results calculated by the software through entering building characteristics in the optimization part with suggestions relating to the elements in the "calculations" in optimization part.

Using the energy simulation application, which can be learned and used easily enables practitioners of building-related disciplines such as architecture engineering, civil engineering, mechanical engineering, and construction to model a building from different aspects of design and construction. Such applications, along with instructors' experiences, leads to defining a path by which theoretical and traditional instruction concepts can be understood by everyone.

3 Methodology

Engineering community's efforts to reduce energy consumption in the building sector in Iran have led to the development of national building regulations and also the development of BECS energy simulation application. The main research hypothesis was that BECS application, as a virtual project-based learning tool is an effective learning one for construction students. This study aimed to examine the application of construction students' learning and knowledge, who had no work experience in a real environment, to design and construct sustainable buildings considering saving energy consumption (heating – cooling) in a virtual environment. This was possible by using simulation environment and receiving a quantitative output with suggesting efficient building details to save energy consumption.

Participants of this test included 42 undergraduate students of construction at Tabaran Institute of Higher Education in fall 2015. The evaluation was most about the information sources and learning of construction students in theoretical courses, including elements and construction details, knowledge of building materials, building design courses and building heat transfer calculations. First, a residential building with certain conditions was selected for building energy simulation. The building plans were provided for each participant in the form of files with the format of drawing software such as AutoCAD along with a three-dimensional model. Participants were asked to record the project name and general information, including the number of floors and building's useful surface area. In the next step, the building's location was completed by the target city. Cities were classified by simulation database in terms of different climate zones. Then, the type of applied group of buildings was determined according to local building regulations and standards. In the related table in each group, the type of buildings is classified with more details such as residential, commercial, educational, and so forth. After entering the information related to the building, the thermal energy calculation by the simulator is recommended.

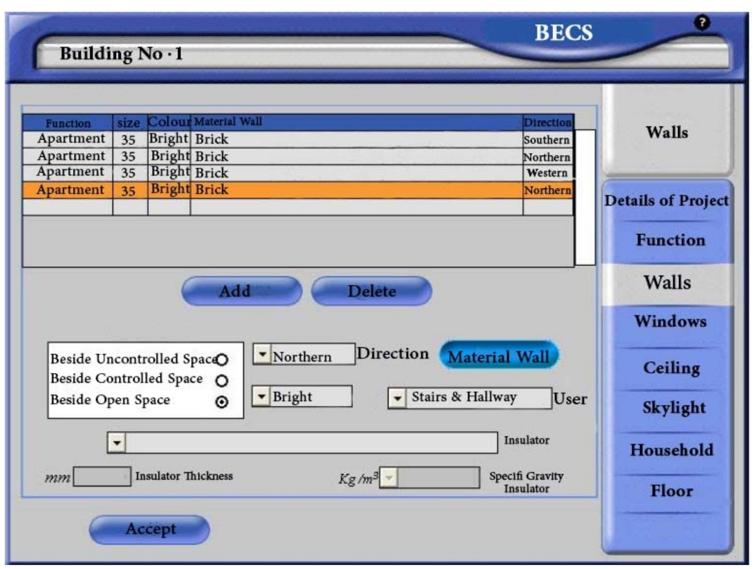

Figure 1: An screenshot of BECS application

In addition, in this simulation application, a part titled DB Viewer, was considered to enter new information (defining new materials, adding a city, defining new username).

When the mentioned format was confirmed, in the next step the type of energy consumption (electric –non-electric) and usage time (continuous –intermittent) and the type of building (villa –non-villa) were determined by the user. Based on the information provided. BECS informs participants the required coefficients to calculate reference heat transfer in different parts of the building in a table. The most important step in working with simulation application was the suggestion part of effective details (Figure 2). These details were portrayed based on the concepts of energy-saving provided in construction curricula. In the suggested resistant materials, participants were asked to design details with the possibility of organizing layers of materials from the outermost to innermost. After selecting materials through which participants entered the suggested layers thickness according to previous knowledge, BECS provided thermal conductivity coefficient and thermal resistance. In the next step, materials were entered. Based on the materials selection, the R value (the overall thermal resistance,m^2.k/w) and U value (the overall heat transfer coefficient, w/m^2. K) were calculated and indicated by the BECS(Figure 3).

At the end, the proposed details were prepared in the form of images. In this case, all building components had to be specified, so that related calculations were performed. The building accountability can be controlled.

In the stage of building condition, and in the case of lacking accountability the details should be replaced so that the building is accountable for thermal needs. To achieve favorite results, participants could repeatedly select different materials to finally suggest the most appropriate details with optimum heat resistance and low thermal coefficient. In every output, the BECS application informs whether or not the proposed details are acceptable for sustainable building thermal load. It was important that, after several decisions about design techniques, best materials were selected to achieve more efficient results. In addition, prediction of building efficiency should be controlled by designing and calculating before the actual construction. Wrong decisions will lead to the building thermal inefficiency.

After several failures in the selection of various materials and their location to meet the thermal requirements of the building, it was possible to evaluate participants' ability to use their knowledge. To evaluate the effectiveness of BECS, a pre and post-test was designed with 21 items in three thematic sections A, B, C. Section A questions consisted of general definition and terms of energy saving. In Section B, questions investigated the effect of using thermal-resistant materials in the design of building details. In this section, thermal insulation and various ways of designing details of shells such as walls, roofs, floors, and facade in different sides of the building were provided. Students could select various materials from the default materials in the application, and, thus, they could compare the

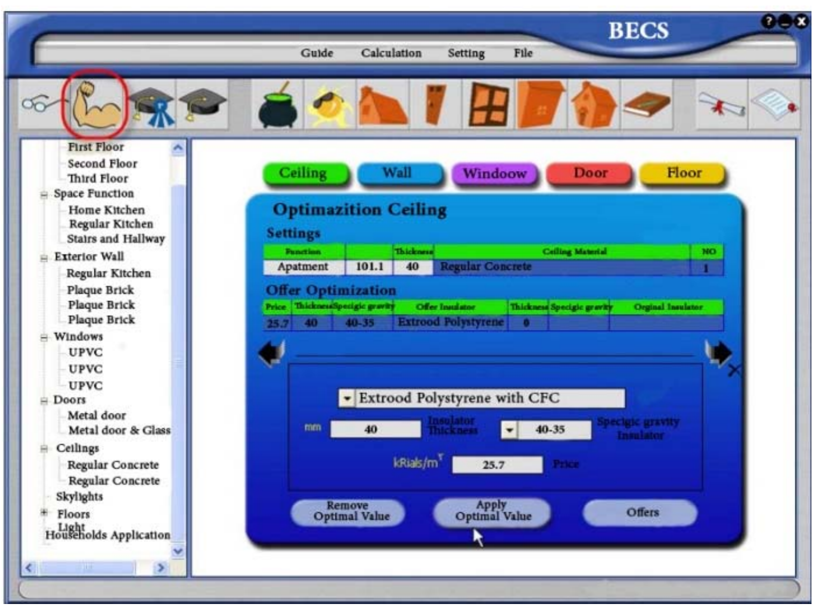

Figure 2: An screenshot of BECS optimization

effect of their selections in the proposed details on thermal resistance. The effect of light diffuser area, the location, calculation of thermal resistance, and profile selection of different materials and thickness of walls were provided in Section C. In order to quantify the participants' perceptions in pre and post-test, a five level Likert scale(very low: 1 to very high: 5) was used. Before playing the BECS, the pre-test questionnaire was distributed to assess students' theoretical energy optimization perceptions. The post-test was conducted at the end of working with the simulation application to measure its effectiveness.

4 Results

Participants included 42 students, 57% male and 43% female students among which 28% of female students and 45% of male students had work experience related to their field of study. Although, none of the students were trained outside the class in the field of energy optimization, six students reported previous experience working with simulation applications. Section A of the survey was designed in accordance with general definitions and terms used in energy saving concepts. Through this section, about 90 percent participants rated their knowledge in calculating thermal coefficient and estimating the efficiency of building energy requirements as low or very low. This indicated the lack of enough understanding about the energy calculations based on building components. In section B, 88% of participants in pre-test rated their knowledge on the effect of using different thermal insulation materials as low or very low. After playing simulation, 85% of participants rated their understanding on subjects, provided in this section, as high or very high. Overall, 80%of students rated the necessity of integrating different types of simulation applications in construction curricula as high or very high. Fifty four percent of participants showed high tendency for replacing the related courses in construction programs with the simulation applications. On average, 69% of participants rated their experience on using BECS application as "satisfied" or "very satisfied".

A paired sample t test was utilized to determine the mean difference between the retrospective pre and post-test scores for each of 21 questions at a significance level of 0.05. As shown in Table 1, there was a statistically significant different between pre and post situations. This indicates that BECS has been an effective simulation application for Sustainable Design and Construction education.

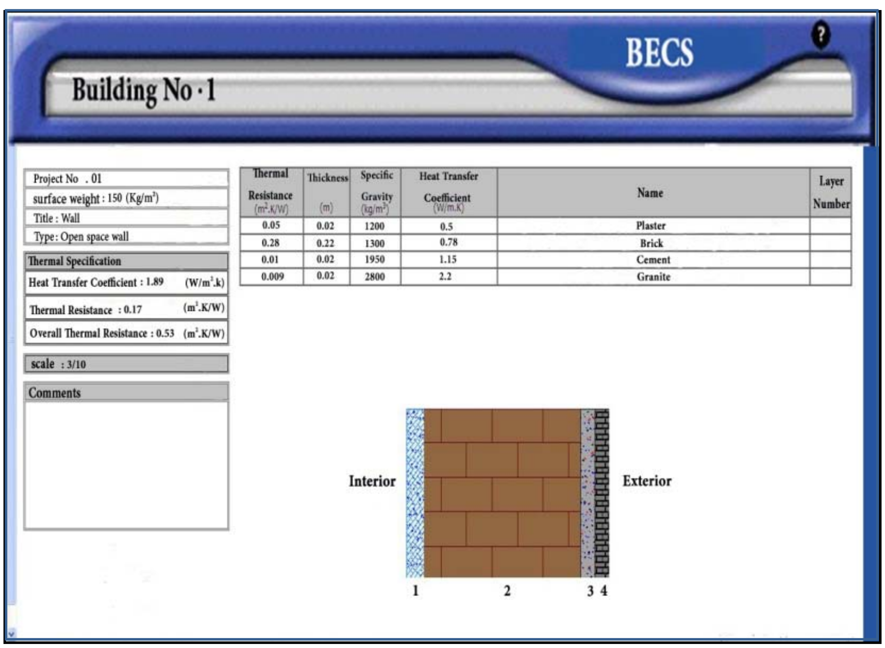

Figure 3: An screenshot of BECS details

Table 1: Paired Sample t-Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Post 1 - Pre 1	2.024	1.179	.182	1.656	2.391	11.126	41	.000
Pair 2	Post 2 - Pre 2	2.238	1.165	.180	1.875	2.601	12.453	41	.000
Pair 3	Post 3 - Pre 3	2.071	.997	.154	1.761	2.382	13.460	41	.000
Pair 4	Post 4 - Pre 4	2.143	1.181	.182	1.775	2.511	11.763	41	.000
Pair 5	Post 5 - Pre 5	2.310	1.093	.169	1.969	2.650	13.695	41	.000
Pair 6	Post 6 - Pre 6	2.357	1.226	.189	1.975	2.739	12.458	41	.000
Pair 7	Post 7 - Pre 7	2.381	1.125	.174	2.030	2.732	13.714	41	.000
Pair 8	Post 8 - Pre 8	2.000	1.169	.180	1.636	2.364	11.091	41	.000
Pair 9	Post 9 - Pre 9	2.381	1.229	.190	1.998	2.764	12.558	41	.000
Pair 10	Post 10 - Pre 10	2.214	1.353	.209	1.793	2.636	10.605	41	.000
Pair 11	Post 11 - Pre 11	2.095	1.322	.204	1.683	2.507	10.274	41	.000
Pair 12	Post 12 - Pre 12	2.049	1.161	.181	1.682	2.415	11.301	40	.000
Pair 13	Post 13 - Pre 13	2.262	1.149	.177	1.904	2.620	12.759	41	.000
Pair 14	Post 14 - Pre 14	2.238	1.055	.163	1.909	2.567	13.751	41	.000
Pair 15	Post 15 - Pre 15	2.238	1.246	.192	1.850	2.626	11.644	41	.000
Pair 16	Post 16 - Pre 16	2.143	1.299	.200	1.738	2.548	10.694	41	.000
Pair 17	Post 17 - Pre 17	2.167	1.057	.163	1.837	2.496	13.281	41	.000
Pair 18	Post 18 - Pre 18	1.929	1.135	.175	1.575	2.282	11.015	41	.000
Pair 19	Post 19 - Pre 19	2.024	1.239	.191	1.638	2.410	10.583	41	.000
Pair 20	Post 20 - Pre 20	2.214	1.094	.169	1.873	2.555	13.117	41	.000
Pair 21	Post 21 - Pre 21	2.619	1.125	.174	2.268	2.970	15.085	41	.000

Participants were also asked to describe the strengths and weaknesses of the simulation application. The lack of default details in the application was reported as its main disadvantage. The strengths included the ease of calculations, the total estimation of building thermal requirement, control of all changes on the design and details in the calculation of building thermal resistance with only limited knowledge, output of proposed details, and the possibility of designing the building with optimal energy consumption.

5 Conclusion

Several educational learning theories support teaching with the use of simulation in construction education. In recent years the use of simulation in construction education has been growing. The results of studies indicate that this approach has been effective in creating interest and attraction among students and increases their satisfaction and confidence [24]. Compared to traditional models, simulation is less efficient in learning mental principles and skills, but it is very effective in training practical skills, especially when mental concepts and principles were previously taught with other methods. Different types of simulation can be used in construction discipline, which require further studies. There are challenges for using this learning approach that can be solved to some extent with proper planning. Educational institutions can pave the way for the development of simulation applications by using their potentials. Despite challenges, this method has many advantages and is a very effective method in training communication and practical skills, critical thinking and decision-making. Given the special emphasis on cost and operational issues in the construction field, the use of this approach in teaching construction students seems essential and should be pursued more seriously in the construction courses planning. Although the results of this study indicate a statistically meaningful difference between before and after exposure, more research should be conducted to generalize the results. However, construction simulation can be considered as a rich supplementary tool in sustainable construction education.

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