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Original Article

Teaching energy simulation in the architectural design studio: An experimental approach

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Abstract

The teaching methods driven by simulation and other analysis tools are on the rise. Since the methods differ by course outcomes and student technical capabilities, the stage at which to involve simulation or analysis tools varies by instructor. This paper explores the introduction of energy simulation in an architectural design studio course. The study emphasizes on quantifying energy performance during the earlier phases of design. A group of students in two classes were introduced to learning an online energy simulation tool, and the resulting energy performance per student was documented. A wrap up presentation took place to compare energy performance across the proposed schemes. A follow up questionnaire was distributed among the students to collect feedback on several aspects that can enhance both the teaching and learning methods. Students were also surveyed on the value of the tool during the design process. The results of this experimental approach indicate a strong preference to use simulation tools during the early phases of the design and recommendations of suitable building forms. It also includes student feedback and recommendations to assist in future course instruction..

I- INTRODUCTION

The ability to produce energy efficient proposals within the architectural design studio is becoming a requirement more than an option. In addition to the traditional course outcomes of an architectural studio, there is an emerging need for the current students to quantify the performance (please confirm) of their design proposals while balancing all other requirements. “On what basis is this particular building form proposed?” This is a general question to be resolved during the studio journey; it requires the student to justify decision making by using conceptual diagrams, verbal presentations, written research, theory, and many other forms of expression. Is the answer “form follows function” or “conserve energy first” or a hybrid of both?

Similar to many countries, Egypt is facing energy challenges in many sectors, as a result, conservation efforts as well as a development of a new building rating system is awaiting deployment. In addition, several universities are re-structuring their programs to advance the energy efficiency agenda and sustainability as a main priority across the curriculum, offering a wide variety of graduate degrees, diplomas and certificates with emphasis on the environment and especially on sustainable technologies. To respond to this demand, an architectural studio taught in an Egyptian. institution offering an undergraduate program was restructured to integrate energy simulation with design development within “Sustainability in Architectural Design” studio where issues relevant to both design innovation and energy efficiency are offered to undergraduate students who are considered half way in their program, and near the start of their architectural design experience. A primary objective is to quantify energy performance for the proposed design.

The students had taken a course on “Environmental Design Systems and Controls” however, this architectural studio was their first attempt to apply and integrate strategies to deliver a project, to quantify its energy performance as the design is developed, and finally to comprehend and analyze the generated data to benefit the design process.

This paper reports on the initial steps to redesign, structure, and test this integration using an experimental “learning by doing” approach and introducing a building performance analysis tool that is available online for free and easy to learn and use in a short time. The main objective was not to produce a design driven by simulation alone, but to introduce the method to the students as an example of what they will go through after graduation working as professional architects.

It’s important to note that many assumptions were made. For example, not all the students are at the same level of technical readiness to understand the difference between modeling and analysis. Our main concern as a teaching team was not to force this method to be the primary design approach. It also should be noted that this work builds on previous experiments and research with similar objectives; however earlier studies worked with a more advanced group of students or differed in the teaching techniques.

Of the earlier works published on this topic, one study put forward three courses (one introductory, one theory, and one practical) to give students opportunities to teach themselves through online technology with emphasis on availability and online learning. All course material was published online, and student licenses for the software were available. This study was done mainly with a Masters' level students[1].

Another study presented the results of a survey on the use of simulation software, which has involved academic and industrial members of the Simulation Study Group of the Operational Research Society of Great Britain. Findings of the survey indicated which types of simulation software are primarily being used, the most common application areas of simulation, users' opinion about software, and possible ways of improving simulation software[2].

The issue of quality was addressed by Hansen *et al*. in courses which were taught at three levels: 2nd year undergraduate, 1st year masters, and final year masters/starting Ph.D. There was a theoretical as well as a practical part. The instructors believed that domain knowledge is paramount for working with Building Performance Simulation (BPS) software and that an ability to assess quality assurance is also important. In the undergraduate course, students carried out part of the BESTEST procedure on commercial MS Windows-based building simulation software. The results of many simulated buildings were compared to results from validated and verified BPS software to check for errors and variances[3]. On the educational requirements to run simulation tools, a study by Pedrini *et al*. recommended that students should be introduced to scientific and technical foundations for the use of BPS tools during their education to learn how to integrate them in their own practice[4].

Soebarto investigated the experience of teaching building simulation to a Masters' level students in architecture school to simulate energy performance and comfort levels in their design projects. Students were asked to present shade/shadow analysis and comfort levels, based on which their design was adapted. One of the main problems faced in teaching software was the lack of acquaintance with the basic processes, especially with non-visual applications such as infiltration. This led to unrealistic numbers being put to improve simulation results. Students also did not consider environmental factors as sufficient to change their design; therefore, willingness to learn was an important factor in the success of the experiment. This is very relevant to the problems that we might face in our own experiment. An example of students work was given[5].

In a university in Brazil, a paper addressed the problems of a Brazilian university (UNICAMP) and its architectural program which lacked a bioclimatic design studio. They started by a brief coverage of using simulation tools in Brazilian universities and went on through a traditional research phase before beginning the design phase. During the design phase, they referred to a simulation expert, and modified their initial design based on the results. The results of this experiment showed that students preferred to simulate day lighting as opposed to thermal effects and students were encouraged when they saw modifications to colleagues' designs[6].

Another study investigated the academic use of thermal analysis software "ECOTECT". ECOTECT was the most common, along with simulation tools such as "Energy-10", "RADIANCE" and "CONTAM". In conclusion, the author stated that a survey should solicit feedback from firms to find out their preferred software to be taught in schools[7].

On the issue of integration, a paper was concerned with the "integration of building performance simulation within a higher-education environment. The authors investigated when and how building performance simulation (BPS) should be introduced to architecture and engineering students. Thus, they put together a course for both architects and engineers, that consists of a class and studio. In the studio, students deal with three problems. One of them was an upgrading of an existing building on campus. The aims of the course were two-fold: first, to establish a working relationship between architects and engineers on environmental issues before graduation, and second to encourage incorporation of BPS tools early in the design process. The authors also set out questions that this experiment raises for future research[8].

The authors of a similar paper investigated the suitability of ECOTECT as a design tool to be used by architecture students. The teaching of ECOTECT was included as part of three design courses at several levels of students' architecture education and several factors were assessed including their modeling strategies, effect of strategy on weight of file, the level of improvement in final projects due to ECOTECT, and the interest of students themselves. It was found that students were far more interested in learning building physics concepts through practical experience as opposed to traditional lecturing. However, the extent of their learning is dependent on the teacher's ability to include theory, when needed[9].

In a related study by Reinhart *et al.*, the authors expressed their belief that the key problems in building simulation are that architects do not know how to read energy simulation outcomes or how to incorporate them into design. The authors produced a game where students were given several options and had to collaborate to design the most energy-efficient building within cost limits in a 90-minute exercise. This was tested on Design Builder and the simulation results returned to students to improve their design The result was a more engaged and interested classroom with students who became much more interested in simulation software and environmental design in general. It is important to note the need for quality control in future experiments to avoid guesswork by students[10].

Finally, a paper started with covering the key concepts relevant to building energy dynamics. It then proceeded to outline three teaching approaches: first, existing modeling software in which an instructor taught and students followed with their own models; second, a custom simplified modeling approach in which there is an input and output screen and changes made in the input reflect in the output; and third a game-based approach similar to that carried out by Reinhart *et al.* It concludes by comparing all three approaches and presenting the game-based approach as most conceptual but most favorable so far[11].

II- METHEDOLOGY

As mentioned in Debaillie's study, three methods of instruction were explored: "e-Quest in class," "Back-of-the-Envelop" and "Game based." This paper proposes a learning-by-doing approach allowing the students to individually interact using their own design project during class and experiment with simulation tools focusing on a single design criterion so as not to be distracted by the overwhelming number of variables. Because of the students' background in building physics and systems and their general technical ability to work with the tools in a short time, it was understood that they would not be ready to conduct a full scientific energy simulation exercise. This exercise is their first hands-on training and was proportional to their abilities given their stage in the program. Therefore, an easy to use simulation tool was recommended for instruction and the installed programs were as follows: EnergyPlus v.7.2; Sketch Up Pro 8, and Open Studio legacy add-in extension. Students were first allowed to install the programs on their own laptops, a two hour tutorial was given, and a follow up discussion took place to make sure all questions were answered. A questionnaire was circulated before the training and another after the training to measure the student acceptance of this method for design development and to get written student feedback to advance the development of the course in the future.

Students were given a single task to experiment with their proposed building form to generate the optimum compactness possible. Gratia and De Herde previously stated the heating load of small buildings can vary by around 25% from the most compact to the most sprawling designs[12] where the Compactness "C" coefficient is measured as the ratio of building volume "V" to surface area "S", a typical metric often used in Europe[13]. Students used plans developed during the schematic design stage, and each was asked to simplify the building form and experiment until reaching the best compactness ratio. Many of the simulation assumptions were standardized across the students to isolate all other factors and focus only on the relationship between form and energy consumption.

III- EXPERMENTATION AND RESULTS:

In advance of conducting the training, a "Before" questionnaire (Questionnaire A) was distributed, and an "After" questionnaire (Questionnaire B) was distributed after the completion of the exercise and submission of results. The objective of Questionnaire A was to map out the student skills and familiarity with building simulation, background knowledge, and hands-on training. The results of the questionnaire revealed the following: 67% of the students had previous training on thermal analysis tools. The breakdown of the tools show ECOTECT as the main tool used, as shown in (Fig.1).

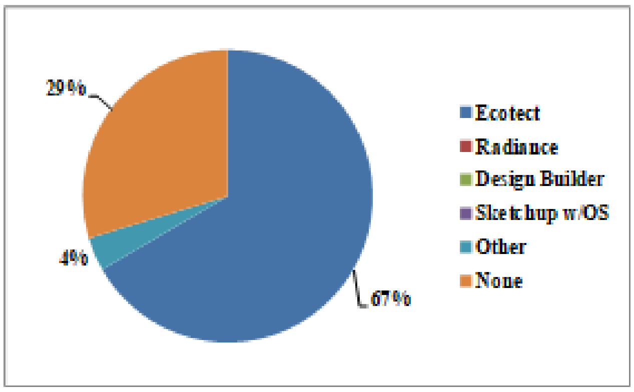

Fig. 1: Tools generally used by the students

On the areas of application, 29% used it as part of a previous course on environmental controls but not in a design specific task. Another 15% applied it in day lighting studies, and about 4% used to present he weather patterns only. In other words, a staggering 52% studied the tool in a tutorial but never used it or attempted to use it during a design project (Fig.2).

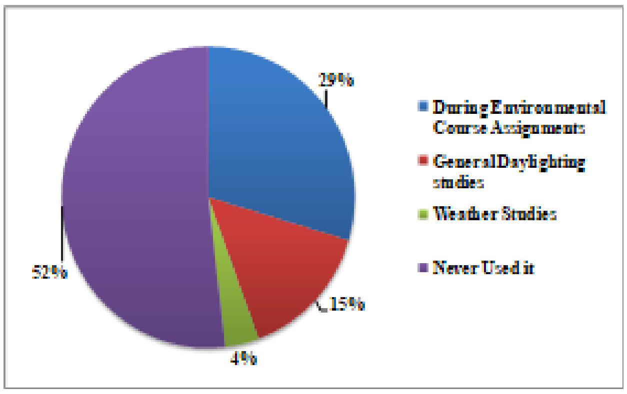

Fig. 2: Common areas of application by students

On asking who benefits from using the tools, almost 68% reported that architects are the main beneficiaries (Fig. 3).

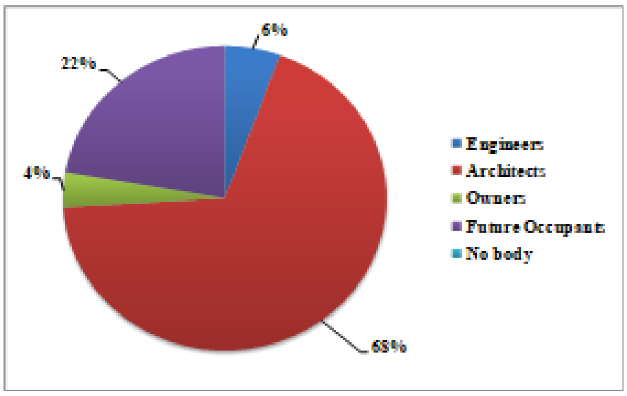

Fig. 3: Student's opinion on the beneficiaries of using this tool

On asking when to introduce the tools to the students and in which stage, a nearly equal split was observed between the conceptual, schematic and design development stages (Fig.4).

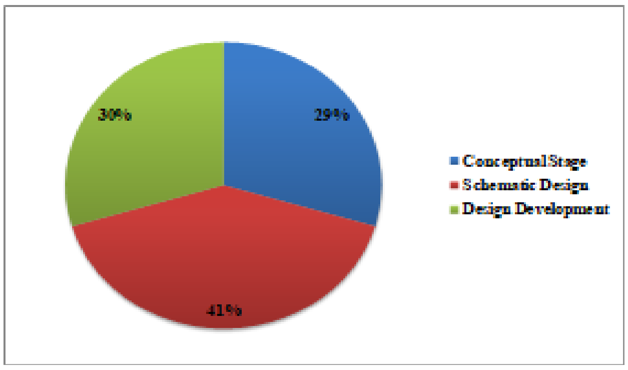

Fig. 4: Stage to involve simulation tools

On asking which areas of the project would be highly impacted by using energy simulation tools during design development, a split decision was observed among the students with nearly equal percentages choosing the architectural form, choice of materials, and the design process itself (Fig.5).

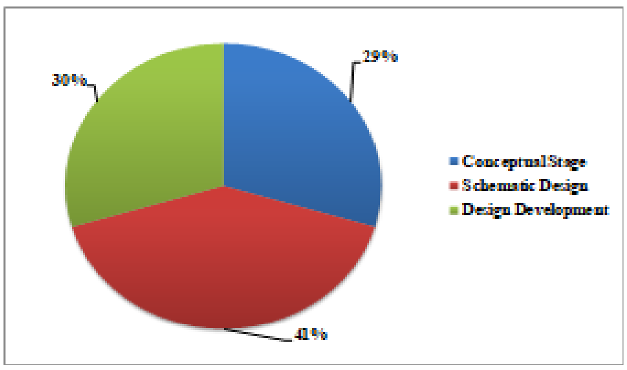

Fig. 5: Areas of impact during design development

On the question on whether the energy simulation tools will limit the ability of the students to design creatively, 26% of the class agreed with the assumption of the limitations. To understand the reasons that discourage students from using energy simulation tools, 39% of the students reported that it requires prior knowledge to operate successfully, while 35% and 26% thought it's too complex to use or doesn't help with all aspects of the design process (Fig.6).

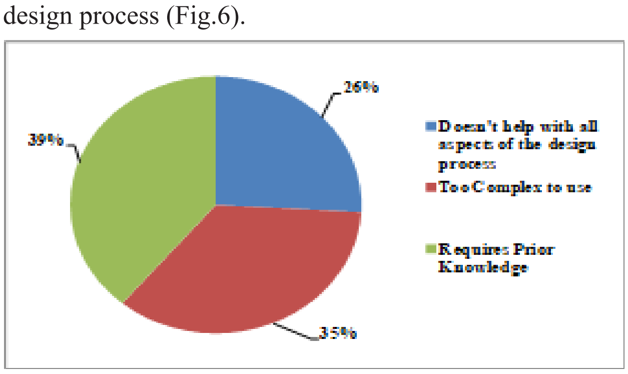

Fig. 6: Reasons that discourage the students from using the tools during design development

Finally, students were asked to predict what building form is the most compact and therefore, the most energy efficient. 22% selected form "C" shaped as a horizontal U to be the most compact and energy efficient (Fig.7).

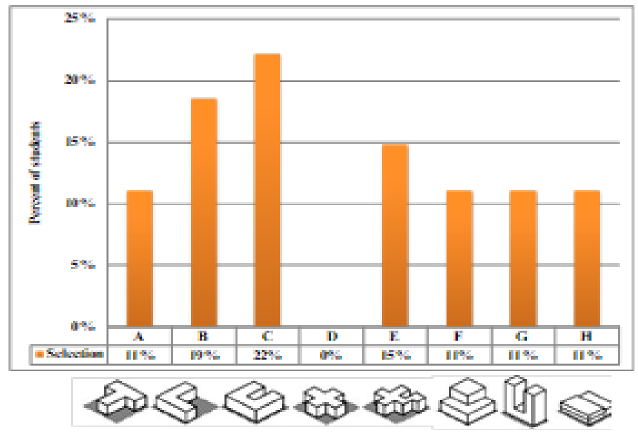

Fig. 7: Student's prediction of compact forms prior to training

Students were asked to consider default assumptions (Table.1) with respect to the simulation itself to focus primarily on the relationship between building form and energy consumption. The following assumptions were common across the students:

Table 1: Default assumptions

Number of People/100m2	5.38
Lighting Power density (W/m2)	10.76
Electric equipment density (W/m2)	10.76
Outdoor Air per Person (L/sec/person2)	2.36
Outdoor Air per Area (L/sec/m²)	0.30
Infiltration rate (ACH)	0.5

On a scale of 1-10, students were asked to rate their capability of using the tools before and after training. The majority of the class reported a low to moderate capability while a small percentage reported a moderate to high capability of using the tools before training and an increase in capability was observed after training (Fig.8).

Fig. 8: Comparison of capability before and after training.

Immediately after training the following results were observed: 55% of the students agreed to the introduction of the tools during the schematic design phase, and 52% agreed that experimentation with tools at the individual level is more beneficial to the students than group work. This was followed by a question on the methods of teaching, and 67% preferred a direct hands-on experimental approach with specific tasks relevant to the project design development while 14% preferred a “Game approach,” 12% preferred a “Traditional lecture lab with homework assignments,” and finally, 6% preferred “Online tutorials”(Fig.9).

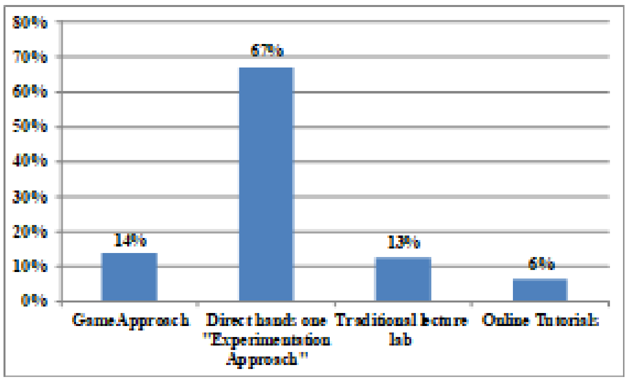

Fig. 9: Preferred method of teaching

At the end of the training, students were given a task to study the compactness of their proposed building forms. As mentioned previously, the majority preferred form “C” and after training it was validated that it is the most compact form followed by forms “B” and “E” (Fig.10).

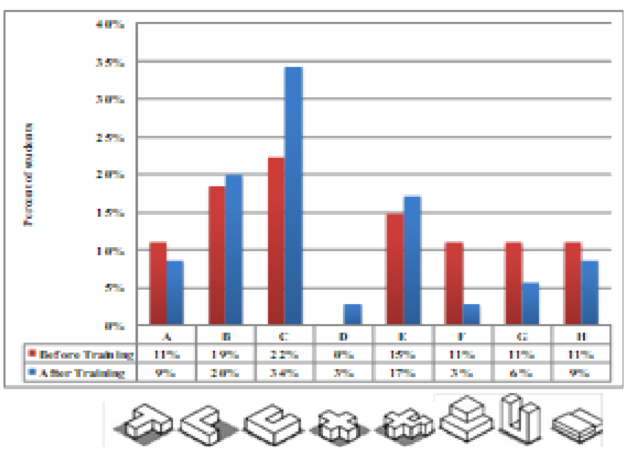

Fig 10: Actual results of student’s exercise on compact forms

IIII- DISCUSSION

The approach presented in this paper was inspired by previous teaching approaches of energy simulation in the class room. The experimental approach presented in this paper was to overcome three main challenges that often exist in the classroom in the classroom, Based on our experience, a thorough data understanding of the input and output variables required to complete a successful energy simulation process, scale of exercise to complete in time and in relevance to the ongoing design project, and introduction time of utilizing energy simulation both at the program level and the project stage.

We have utilized an online tool that is easy to download and we were careful to make sure that student completed the exercise individually as it has been observed in the past that group work may work against non-participating students, which will in turn impact the overall final evaluation of students. This experimental approach depends on incremental tasks given to students in lieu of a full scale simulation; as a result, many of the assumptions were common across all participants to make sure secondary errors were eliminated during the modeling process. The following table (Table 2) describes the design guidelines generated from the student experiments in terms of compactness data, volume, surface area, EUI, primary and secondary preferences for building form.

Table 2: Baseline results (design guideline)

“Built up Area “required	5,445 m3
Volume	18.76 m3
Surface Area	10.25 m3
Compactness	1.8
(Energy Use Intensity (EUI	198
Primary Preference	C
Secondary Preference	B, E

V- CONCLUSION

During the exercise, the students repeatedly asked whether to adopt the building form “C” as the primary preference, which in turns started a debate between a “function follows form” to “function and form follows tool,” an issue that many of design studio instructors would try to avoid. But, is it problematic for architectural students to think with tools as primary design approach? There is no simple answer. Architectural students understand from repeated instruction the importance of efficiency and carbon emissions. We observe programs that require students to certify their projects using multiple rating systems while in class; therefore, the growing need for architectural students to use energy simulation tools is critical. What we are sure of is the growing need and importance to train students to understand the importance of their design decisions on the overall energy consumption early in the design process and to “simulate” real life office environments so they are ready to integrate in high performance building projects in the future. Future phases of this work include the incorporation of student feedback, increasing the assignments beyond just the calculation of compactness and the relationship to energy consumption, and expanding the analysis to more than one building zone.

VI- REFERENCES

[1] Hensen, J.L., *et al.*, Introducing Building Energy Simulation Classes on the Web. Transactions - American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), 1998. 104: p. 488-494.
[2] Hlupic, V., Simulation software: a survey of academic and industrial users. International Journal of Simulation, 2000. 1(1-2): p. 1-12.
[3] Hensen, J. and M. Radosevic. Teaching building performance simulation - some quality assurance issues and experiences. in PLEA 2004 - the 21st Conference on Passive and Low Energy Architecture, 19 - 22 September, Technische

Universiteit Eindhoven, p. 1209-1214. 2004.
[4] Pedrini, A. and S. Szokolay. The architects approach to the project of energy efficient office buildings in warm climate and the importance of design methods. in Building Simulation. 2005.
[5] Soebarto, V.I. Teaching an energy simulation program in an architecture school: lessons learned. in Proceedings of the Ninth International IBPSA Conference. 2005.
[6] Delbin, S., V.G. da Silva, and D. Kowaltowski, Teaching for integration of building energy simulation in the design process. 2007.
[7] Haberl, J.S., SimBuild survey: Academic use of simulation software. Proceedings of SimBuild 2008 Conference, Berkeley, CA., 2008.
[8] Charles, P. and C.R. Thomas. Building performance simulation in undergraduate multidisciplinary education: Learning from an architecture and engineering collaboration. in Proceedings of Building Simulation. 2009.
[9] Palme, M. What Architects Want? Between BIM and Simulation Tools: An Experience Teaching Ecotect. in Proceedings of Building Simulation 2011:12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November. 2011.
[10] DeBaillie, L. Teaching Commercial Building Energy Dynamics through Simplified Energy Modeling Tools. in The American Council for Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings. 2012. Pacific Grove, CA.
[11] Reinhart, C.F., *et al*., Learning by playing–teaching energy simulation as a game. Journal of Building Performance Simulation, 2012. 5(6): p. 359-368.
[12] Gratia, E. and A. De Herde, Design of low energy office buildings. Energy and Buildings, 2003. 35(5): p. 473-491.
[13] Straube, J. The Function of Form: Building Shape and Energy. High Performance Enclosures, Insight-061., 2012.