ARCHITECTURAL STUDENT’S ATTITUDE TOWARDS BUILDING ENERGY MODELING: A PILOT STUDY TO IMPROVE INTEGRATED DESIGN EDUCATION

Shan He, Ulrike Passe
Department of Architecture, Iowa State University, Ames, Iowa, United States

ABSTRACT
With the steady development of building energy simulation software, the user groups expand from engineers to architects. In the meantime building performance simulation is considered to enable students to gain valuable insights into complex building performance. Considering both the job market opportunities and students’ request for tools enabling sustainable design decisions for energy efficiency, a new building energy simulation modelling elective was established in an NAAB accredited Architecture program. Six different software packages were introduced and utilized to develop the design of an office building in a humid subtropical climate. The course target is to practice integrated design concept with the introduced software. For the students, computational modelling of building energy performance integrated from the conceptual design level to design development stage is still new. To understand the students’ attitude to building energy modeling, an investigation was conducted collecting data of students’ attitude to building energy simulation concept, different software packages and class pedagogy.

By analysing the collected data, the students’ attitude to different software packages and reason was identified. The suggested refinement of the energy education for architectural students is a potential contribution to architectural pedagogy and practice for integrated design. The study can also be beneficial for the software industry to receive feedbacks, which can support the improvement of energy simulation interface for future architects.

INTRODUCTION
During architectural education, design feedback is crucial to students’ learning and progress. The hypothesis of the investigation presented here is, that building energy simulation can provide additional support to the traditional design feedback, which otherwise comes from instructors, peers, juries and self-evaluation. Upon the students’ request, a new course open to both undergraduate and graduate students is offered as an option at an architectural degree program accredited by United States National Architectural Accrediting Board (NAAB). This course started from Spring 2015 onwards to introduce students to building energy analysis through climate, day-lighting, natural ventilation, whole building energy performance from conceptual design to design development stage. The class was designed to place more emphasis on practicing integrated design and developing a design argument, in opposition to train architectural students to become mere energy modelling expert.

<table>
<thead>
<tr>
<th>#</th>
<th>Weeks Spent on</th>
<th>Software Name</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Climate Consultant</td>
<td>Climate</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Sefaira Architecture</td>
<td>Conceptual level, whole building energy</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Autodesk Ecotect</td>
<td>Conceptual level, shading</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>MIT CoolVent</td>
<td>Conceptual level, natural ventilation</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Integrated Environment Solutions Virtual Environment (IES VE)</td>
<td>Design development, whole building energy</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>DIVA for Rhino</td>
<td>Design development, daylighting</td>
</tr>
</tbody>
</table>

A comprehensive and validated simulation tool that integrates across scales from conceptual level to design development level is still missing. Although multiple software have the capacity to simulate whole building energy performance, in practice architects and energy modellers are still using different tools to differentiate the simulation scope during conceptual design and design development. An example from SOM’s integrated design group shows, that architects are still using conceptual modelling tool like Ecotect in 2015 even as its support from Autodesk stopped after 2011. On the other hand professional energy modellers are using software like IES VE for design development. The approach of introducing integrated design in this class was thus identified as using different software...
to evaluate different part of building performance, anticipating that the achievement of a comprehensive understanding of all simulation algorithms is not practical for architectural students.

Six software packages as shown in Table 1 were introduced to students in a chronologically order that mirrors possible integrated design workflow: From understanding climate to conceptual design integration and more detailed design development. The students meet with the instructor once every week with a 2.5-hour long combination of lecture and lab. At the end of the semester the students were expected to work in groups of 1–4 and make energy efficient design proposals for the IBPSA 2015 international student simulation competition (Manu et. Al, 2015), which requested proposals for a mid-size office building located at a sub-tropical climate zone using hybrid ventilation.

For the class grading, students are expected to develop a clear design argument with the assistance of building performance simulation and complete progress report on different software assignments.

As a pilot class without previous experience there are a lot of uncertainties for the instructor to explore in collaboration with the students. To avoid bias as much as possible an independent researcher carried out the following data collection to understand the students’ attitude towards building energy simulation and inform the future class development and software development.

DATA COLLECTION METHOD

The investigation designed by the independent researcher includes three main data collection methods: questionnaires, individual interviews and observation of final class presentation. The data collected remain anonymous to the instructor until the end of the semester after grading. The participation in the data collection efforts was voluntary for the students. Each student participating in the complete data collection received a $10 US dollar gift card as research incentive. All the data presented in this paper were released by the students with written consent.

Questionnaire:

Seven sets of questionnaires were designed in total: the first questionnaire was submitted close to the beginning of the class and the other questionnaires after each of the six sessions. These questionnaires were designed to reveal general attitude with Likert scale survey and several open questions. The pre-survey was designed with 14 questions to collect students’ information on:

1- Demographic info;
2- Amount of time spent on computer simulation before this class;
3- Attitude towards traditional design feedback;
4- Expectation for building energy simulation and this class.

Post Surveys focus on the software usability and students suggestion for the class pedagogy using 3 short questions.

1- A Likert scale rating of 6 attributes “it is helpful”, “it is easy”, “it is flexible”, “it has adequate power”, “it is stimulating” and “I am satisfied” (Chin et al, 1988).
2- An open question to collect additional comment about the software.
3- An open question to collect suggestions for the class pedagogy.

Individual interview

A 30min one on one interview with each student was conducted close to the end of the semester. Individual interview was conducted as supplement data collection to understand the survey responses better. It is found that with the surveys there are a lot of undecided choices, conflict and blank responses. And students’ attitude is dynamic along the way. Thus the interview is the chance to obtain a comprehensive understanding of their experience with this class.

Final Presentation

Observing students final presentation helps to understand how students make design decisions with the software and how they use it to support their design argument.

DATA ANALYSIS

The investigated class started January 12 and ended on April 10, 2015. 13 students enrolled in the class. One student chose not to participate the whole data collection. The other 12 students spread across architecture undergraduate 3rd year to graduate 3rd year, among which 8 students participated the full data collection, other 4 of them participated part of the data collection.

Table 2 Questionnaire Statistic

<table>
<thead>
<tr>
<th>Survey Name</th>
<th>Survey Start Date</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Survey</td>
<td>February 9, 2015</td>
<td>12/13</td>
</tr>
<tr>
<td>Post Survey 1-</td>
<td>March 27, 2015</td>
<td>12/13</td>
</tr>
<tr>
<td>Climate Consultant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Survey 2-</td>
<td>March 27, 2015</td>
<td>12/13</td>
</tr>
<tr>
<td>Sefaira</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Survey 3-</td>
<td>April 10, 2015</td>
<td>10/13</td>
</tr>
<tr>
<td>Ecotec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Survey 4-</td>
<td>April 10, 2015</td>
<td>8/13</td>
</tr>
<tr>
<td>CoolVent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Survey 5-</td>
<td>April 10, 2015</td>
<td>8/13</td>
</tr>
<tr>
<td>IES VE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Survey 6-</td>
<td>April 10, 2015</td>
<td>8/13</td>
</tr>
<tr>
<td>DIVA</td>
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</table>
For a comprehensive analysis the following section combines the questionnaire and interviews.

**Pre Survey**

Although hand drawing and physical models are still considered to be very important by the students, computer aided design is also very popular among the investigated architectural students from different years. Understanding how students spent their time with the computer helps to identify where energy modelling could be situated during design process. Based on the data collected from survey and interview, it is not surprising to find that students are spending their majority time during design studio with a computer interface. With the understanding, that design thinking is present during the whole design process, it is obvious that the students already start to integrate their design thinking with computer simulation. Although it is unclear whether the students receive more stimuli from traditional design method or computer simulation, it is reasonable to predict that the demand for comparing different design iterations within building performance simulation software could rise significantly in the near future.

Pre survey responses show that rendering, wireframe drawing and surface generation dominate their time spent with computer software. During the interviews, most students explained that energy analysis and daylight analysis are only carried out when required by a course. The energy and daylight analysis software they have used before are Climate Consultant, Sefaira and Ecotect. Other programs like Autodesk Vasari were also mentioned by the students during interview. All these software mentioned by the students are serving for pre-design and conceptual design stage.

**Table 3 Averaged time spent on computer aided design (12 respondents)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rendering</td>
<td>35%</td>
</tr>
<tr>
<td>Wireframe Drawing and Surface Generation</td>
<td>38%</td>
</tr>
<tr>
<td>Energy Analysis</td>
<td>16%</td>
</tr>
<tr>
<td>Daylight Analysis</td>
<td>12%</td>
</tr>
</tbody>
</table>

In the pre survey satisfaction of computer simulation was discussed in conjunction with the traditional design feedback based on verbal comments. Among all 12 responses to the pre-survey, their satisfaction to different kinds of design feedback is plotted in Fig. 1. It shows that most students are satisfied with instructor, jury review and self-evaluation. More students are undecided about peer review, especially for younger students who have not had a chance to receive much feedback from their peers. During interviews the students explained that they like the instructors’ and juries’ review because of their credibility and the informative communication with them, which is both lacking with the energy and daylight simulation, as part of computer simulation. According to the interview, the credibility concerns regarding energy and daylight simulation come from both their studio instructors and negative reviews on simulation accuracy published in media. The evaluation of not receiving enough useful information from energy and daylight simulation derived mainly from the students’ experience as a user. Their confusion is caused by not understanding the connection between simulation input and output, and challenges of trouble shooting due to software bugs and unfamiliar with the software interface.

Although software interface and bugs are beyond the capability of instructors, this made the class target more clear, which is to build the students’ confidence with the simulation by helping students understanding the strength and weakness of the software.

![Figure 1 Students' satisfaction with different design feedback sources (12 respondents)](image)

It is believed that if the traditional design feedback has limitation in certain areas students may seek additional support from alternative methods like the building simulation software. The goals of traditional design feedback are set to provide students with:

1. Objective Design feedback;
2. Visualization Assistance;
3. Confidence to make design decision;
4. Clear direction about what to improve;
5. Promotion of more design iterations;
6. Chance to get enough feedback

They are summarized from Graham’s study (Graham, 2003) with removing the part of in-person communication skills.

As shown in Fig. 2 in general students are very satisfied with the traditional design feedback. The most negative evaluation focus on “Clear direction about what to improve” and “visualization assistance”. Responses to the open question and interview suggest that the students also need more diverse design feedback: different design processes and the benefit of different processes, sustainable practice in general, how to make design practical and diverse opinions from multiple instructors. A couple of quotes give examples of expectation: “I want to know how the building could actually perform”, “I
want to create powerful image”. These assistance gaps align with the students’ expectation of the building energy simulation class. If class pedagogy and energy modelling software design could bridge these gaps there is a potential to integrate building energy simulation with their everyday design practice.

The last group of question on the pre survey related to the importance and expectation of building energy simulation. Overall 9 out of 12 students think that building energy simulation is important or very important to their design, not only limited to energy simulation and day light analysis. “It’s just how the building could actually perform.” Quote from one of the students. This kind of education was lacking in the studios as the interviewed students pointed out. Students from this class expected that the class can help them to “improve my reasoning for the choices I make”; “understand the impact that different design strategies have on a building, achieving comfort levels with sustainable design” and “understand how to integrate the tools into existing design process. And knowing what the assumptions and strengths of each program are, so we can analyse with clarity and confidence.”

These answers reveal that architectural students do not expect to separate the teaching of building energy simulation from architectural design method and process. Like the traditional synthesis pedagogy of teaching architecture design, building energy simulation has to be integrated in the design process and tailored to design need. The challenge to instructors is to find a balance between the knowledge need to understand software interface and what architectural students need to know. Currently there are obvious different requirements for an energy modeller and a building designer. A contrast paradigm of design thinking between the building thermal simulation tool user and building designer is discussed in de Souza’s study (de Souza, 2012), and simulation community “lacks a comprehensive understanding on the paradigms of knowledge and praxis of the building designer”. In this investigation post surveys on different software create opportunities to solicit the opinions of future architects on this problem.

**Post Survey 1: Climate Consultant**

In general the students attitude towards the usability of Climate Consultant is positive. Most of the students think it is helpful to understand an unfamiliar climate. Concerns focus more on the lack of flexibility with the software output, which is considered not stimulating enough. One student stated that the outputs are “really terrible, basically only gives a screenshot option”. Another student found that the limited thermal comfort standards available with the software are not applicable for the building’s location of the IBPSA 2015 competition.

**Post Survey 2: Sefaira**

The evaluations of Sefaira are more diverse as shown in Fig. 4. The key votes are “it is stimulating and easy”. Though there are high votes for “adequate power and flexible”, sceptical opinion results from the fact that input options are too flexible to get simulation plan under control. A student who has previously used Sefaira, commented that “Sefaira lets you do anything regardless if it is possible or not, I don’t think it is useful”, another student emphasized that “it’s hard to know if your inputs are exactly what you are measuring”. This means that the success of using Sefaira depends on the knowledge level of the user and Sefaira does not seem to provide that knowledge. This is where software tutorial or
instructor teaching has to play an important role. As suggested by one of the students they would need "pre-made matrix of suggested input combinations, so we have a starting point for what has looked before".

**Post Survey 3: Ecotect**

There is no doubt from the students that Ecotect is helpful. The small portion non-positive reviews come from "it is not easy" together with a moderate vote on undecided opinions to other metrics. Those disagreement and undecided opinion on easiness mostly come from students who had not taken or complete the building science and technology class in the undergraduate architecture curriculum, which includes introducing the basic theory of environmental design.

![Figure 5 Software usability evaluation on Ecotect from 10 respondents](image)

**Post Survey 4: CoolVent**

Seven out of eight students agree MIT CoolVent is easy to learn and start a project, and this is the highest easiness rate among all the 6 software programs. However being easy to learn does not solve all the problems. Limited building types available in the CoolVent software library is the main drawback of flexibility. And natural ventilation mechanism is generally lacking in architectural education. During interview, one student mentioned their team were still confused with the simulation results of different floor thickness at the end of semester. They compared two cases with two different floor thickness and they found that the one with thicker floor get better comfort result. They don’t understand why floor thickness can affect natural ventilation but they decided to use the thicker floor in their design. This leads to an important discussion on how the software on conceptual design level should position themselves for designers. For users without enough understanding of natural ventilation, the CoolVent input options are actually educating the users which design parameters could most possibly make an obvious impact on the building performance.

**Post Survey 5: IES VE**

Although the opinions about IES VE are the most diverse among all the 6 software packages, most students interviewed or during class discussion expressed the desire to spend more time learning IES VE, or even a whole semester only for it. IES VE is also the software rated highest on “strongly agree it has adequate power”. Some students commented with words of “incredible”, “really powerful”, “wonderful” in the survey. However, one 3rd year undergraduate student remain undecided at the end of class for not being able to run Microflo and Macroflo, the natural ventilation modules of IES VE. The student explained the reason in detail: “We were able to solve problems with the thermal module Apache within IES VE. But with Microflo and Macroflo we don’t understand the errors at all. We tried to search the specific errors and there are only answers we don’t understand. It looks like to fix those problems we need to know how the software is designed completely.” And those problems not only happened once, they were happening in series and repeatedly which made the student and team feel lost and overwhelmed. This aligns with the zero easiness rating from other students on IES VE. Almost every interviewed students expressed they need a better support for IES VE tutorials.

![Figure 6 Software usability evaluation on CoolVent from 8 respondents](image)

**Post Survey 6: DIVA for Rhino**

The voting for helpfulness and adequate power for Rhino DIVA are all positive. The negative opinion on easiness and stimulation come from the long computing time. With the given time frame in this
class some students can only simulate one scenario which makes DIVA a rendering tool mostly serving for visualization, not testing out different iterations. The positive way to look at it is it can take over or integrate with some of the rendering work that the students already spent a lot of time on.

As for the iteration concern, there is one exceptional student who is fond of computer simulation testing out DIVA with Grasshopper and found it “very interesting with the iterative process DIVA can provide with Grasshopper”. This student’s work is shown in Fig. 9a and 9b. This additional exploration beyond class requirement seems to solve the stimulation problem without enough iteration.

Additional comments from all the 8 students being interviewed reveal that in general students expect to learn more about the logic between software input and output, but about one third to half of their time in the final project were spent on file compatibility and repeatedly building new models in different software. For some students it really made them “feel confused and bad”. It is obvious that some performance simulation software chosen in this class is developed separately from the basic wireframe and surface software (e.g. Revit and SketchUp) where the students start their computational design iterations. Although there are some compatibility work being done between Revit, SketchUp and energy modelling software, students still found different difficulties in the exporting and importing process. A comprehensive building simulation software with good file compatibility is not only a demand from the students, a survey done by Gandhi (Gandhi et al, 2015) also found similar demand from building simulation practitioners working in North America: “reduce the time and chance for errors created by repetitively entering the same information into multiple simulation tools.”

Besides the time spent unwisely on repeated work, almost every student suggested that they need to split meeting once every week into twice. In Spring 2015 the class met once every week for 2h 40min with a combination of software demonstration and lab practice on Friday morning, followed by an architecture studio in the afternoon. Since the design studio is the core class in architecture curriculum, and student think they can practice the software without instructor, they tend to leave early in the morning class for their studio work. This makes the actually meeting sometimes less than planned. Students stated that they want this second meeting to help them on trouble shooting, which is more important than practice simple cases in class. Another suggestion for meeting time is avoid Friday for it’s the most popular time of student field trip. This building energy simulation class is arranged in a fast pace, missing one class could cause students missing one software package. For software like IES VE taught in 3 consecutive weeks, students hope to minimize the time gap between two classes so they can easily pick up what was learnt from the previous one.

**Final presentation**

Final presentation is the best opportunity to understand how the students utilize the design
feedbacks from building performance simulation. The class instructor required the 6 groups performing following tasks in each group presentation:

1. Climate Analysis;
2. Identify design goals and comfort parameters;
3. Resulting challenges to be addressed;
4. Response and strategies based on case studies and examples;
5. Analysis and iteration based on seasonal analysis;
6. Matrix with set points;
7. Workflow based on software;
8. Final design decision.

In general the students demonstrated good understanding of integrated design and capability of utilizing different software in their design work flow: from understanding the climate and establishing goals of occupants comfort, case study of successful building form and techniques, to conceptual design iterations comparison and incremental change of design details. An interesting result found by one of the groups is that the cooling demand calculated by Sefaira is similar with IES VE, which demonstrate a good example of smooth transition between conceptual level simulation and detailed level simulation. The biggest difference in different groups presentation is the amount of successful iterations being carried out and the supportive evidence validating their design decision. Almost every software introduced in this class was found necessary to support the students’ final consolidated design decision. But students still have difficulty to integrate IES VE and DIVA into developing design arguments. All the teams seem to have difficulty with natural ventilation simulation. One group did not get the ventilation module run, which is described in the post survey 5 of IES VE. One group failed to apply their simulation result to their key design argument. And the remaining four groups were only able to run one instance with IES VE Microflo, making natural ventilation simulation more like a visualization tool instead of rational design decision assistance. Limited iteration is also found with DIVA4Rhino due to its long computing time. This shows again that software with steep learning curve and long computing time can affect the development of design argument and miss the opportunity to contribute for design decision.

CONCLUSION AND FUTURE WORK

Pedagogy and class organization

The aim of teaching integrated design concept is challenged by the difficulties found in students’ practice. Although the instructor had no intention of training students into energy modelling specialist, the students on the other hand, feel confused when applying the simulation results without fully understanding the software limits and strength, especially with a complex software IES VE and an unfamiliar topic of natural ventilation. The students supported this class being continuously taught in the future and at the same time pointed out the pedagogy needs some refinement. A balance between the knowledge requirement of understanding software interface and what architectural students need to know at different levels still needs further exploration. Some students proposed to solve this problem with pre-set matrix that has been tested out to get them started. This requires the instructor to narrow down the input alternatives for architectural education.

An additional exploration with Grasshopper and DIVA, and the similar simulation result from Sefaira Architecture and IES VE proves that some guidance on pairing software packages can also improve the students’ learning experience. Considering the extra load for an in-depth education, this class is suggested to minimize the amount of software taught in one semester and select them for students from different years.

In the post surveys the younger architecture students seem to have more difficulty with complex tools and their building science and technology education is not completed. It is better to remove the complex simulation tool like IES VE to fit their learning curve. Senior and graduate students on the other hand, may already have some experience with conceptual level simulation tools before this class and don’t want to repeat simple practice in this class. They also demonstrate a better capability to study independently. Possible solution could be splitting this class into two levels of building energy simulation class:

Level 1: focus on the climate and other conceptual level design software. For undergraduate student year #3 and #4 finishing this class can be listed as requirement to enrol in the second level class.

Level 2: mainly for senior undergraduate student and graduate students, focusing on one or two whole building simulation software.

Reducing the software amount in one semester can also minimize the repeated work spent on file compatibility, and focus on understanding the simulation logic and exploring design matrix. Students can bringing their previous studio project and rethink their design process with this additional design feedback from building energy simulation.

For the class organization, maintaining the 3-credit load for both of the two level classes and meet twice every week should be workable.

Software interface

Demands for the building energy simulation software interface design are found to be:
1. Improve the file compatibility with existing wireframe drawing and surface generating software;
2. Enhance the capability of comparing different design iterations within software;
3. Give more visualization options for output results.
4. For conceptual level design assistance, the allowable simulation input is also educating the users what could make a big impact on the building performance.
5. For advanced simulation tool, prepare architect friendly tutorial with trouble shooting support.

During the interview some students talked about their future plan with energy modelling: explore the software more during summer break and spend more time on energy modelling in their future projects. An oral agreement is established between the independent researcher and the interviewed students for a follow up study. In the Fall 2015 semester, they will be surveyed together with their studio classmates who did not take this energy modelling class. This will help the authors to understand how energy modelling affect their design method and thus improve the class teaching better in future.

ACKNOWLEDGEMENT
This material is based upon work supported in part by the National Science Foundation Grant Number EPSC-1101284. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. This work also receives support from Center for the Integration of Research, Teaching and Learning. Stephen Ray from SOM helped organizing a field trip for the whole class to visit SOM office in Chicago and promoted a discussion between the class and SOM integrated design team.

REFERENCES

Graham, E. M. 2003. Studio design critique: student and faculty expectations and reality. Doctoral dissertation, Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Landscape Architecture in The School of Landscape Architecture by Elizabeth Marie Graham BS, Christian Brothers University.