Building performance simulation in the built environment education: Experience from teaching two disciplines

Priyadarsini Rajagopalan, James P C Wong and Mary Myla Andamon
School of Property, Construction and Project Management, RMIT University, Melbourne, Australia
priyadarsini.rajagopalan, james.wong, mary.andamon@rmit.edu.au

Abstract: Building performance simulations are increasingly being employed in built environment education to assist in the decision making process including design, operation and management. Selecting the ideal tool for building performance evaluation is challenging for environmental design. Because of the complex nature of sophisticated building simulation software, there are no guidelines on how to teach this most effectively and integrate with the curriculum. For effective learning, there should be a perfect balance between ease of use, interaction, steep learning curve, time constraint, compatibility with other drawing software, and flexibility in terms of on-campus and off-campus access. This paper reviews the building performance simulation tools used in built environment education and discusses the experience of teaching students from two different disciplines in the built environment. The study used student feedback and reflection from teaching staff to review the student experience, course development and delivery. The findings of this study will help in the development of curricula and resources for engaging students and improving their learning experience.

Keywords: building performance simulation, built environment education, quick feedback, flexibility

1. Introduction

Building performance simulations are increasingly being employed in built environment education to assist in the decision making process including design, operation and management. Selecting the ideal tool for building performance evaluation is challenging for environmental design. Because of the complex nature of sophisticated building simulation software, there are no guidelines on how to teach these most effectively and integrate with the curriculum. For effective learning, there should be a good balance between ease of use, interaction, steep learning curve, time constraint, compatibility with other drawing software, and flexibility in terms of on-campus and off-campus access.

Previous studies show that to enhance the use of building performance simulation tools among building professionals, the first step is to incorporate the tools in tertiary education curriculum. This paper reviews the building performance simulation tools used in built environment education and discusses the experience of teaching students from two different disciplines in the built environment, in
a constantly changing learning environment. The main objectives of the study are to identify the factors that contribute to the selection of building performance simulation (BPS) tools for teaching students in two disciplines in the built environment in two different universities. The study used student feedback and reflection from teaching staff to review the student experience, course development and delivery. The findings of this study will help in the development of curricula and resources for engaging students and improving their learning experience. This will provide future professionals with access to wide range of knowledge and resources quickly and enhance the use of simulation tools in the architectural practice.

2. Literature review

2.1 Current status of BPS tools

Simulation allows architects and engineers to test ideas and designs before proceeding to construction. There was lot of effort globally in the past few decades to integrate building performance simulation in the building industry. In 2010, the number of tools listed on the U.S. Department of Energy (DOE) Building Energy Software Tools Directory (BESTD) website reached more than 389 (Attia et al., 2012). Many studies were conducted to develop user friendly tools to encourage their use in architectural practice. However other studies show that it still a long way for this goal to be achieved. In a recent survey conducted among practicing architects in four countries, Soebarto et al. (2015) concluded that improving architect’s knowledge about environmental issues and building performance, whether it is through tertiary education or continuous training in practice, is considered to be the first important step to take. To increase the ability of current and future architects and engineers to use simulation in their work, it is important to develop a balanced and well designed curriculum in universities. Many studies (Strand et al., 2004; Soebarto, 2005; Schmid, 2008) have discussed the experience of teaching simulation in the undergraduate architecture and engineering courses. Hensen and Radosavic (2004) highlighted several issues related to quality assurance in building performance simulation that need to be considered in teaching building simulation. In an attempt to replicate the dominant consultant/architect interaction as found in high-quality architecture practices, Charles and Thomas (2009) note that having undergraduate students work with simulation software can help them understand the iterative design process as well as be aware of various physical phenomena involved in building design. To deliver high-quality buildings, professionals involved in design and construction must work in a collaborative manner. To be truly effective at collaboration, the various consultants must have relevant understanding about the vocabulary and the physical processes that take place inside and outside the building.

2.2 Criteria for selecting BPS tools

There are wide ranges of BPS tools available in the market for the architecture, engineering and other built environment related disciplines. Their selection process is challenging for the industry. Most building simulation tools are not adapted to inform design decision-making in early design phases, but tend to focus on evaluation after decision-making whereas architects benefit mostly during this decisive phase while addressing the building geometry and envelope (Attia et al., 2012). There is no clear methodology or outline to assess BPS tool specifications and criteria for developers, practitioners and educators. A number of studies and surveys have been carried out in the past that were concerned with the criteria and requirements of BPS tools. Hong et al. (2000) suggested four selection criteria including
usability, computing capability, data exchange capability and database support to select BPS tools. Weytjens et al. (2012) analyzed the architects’ preferences for a simple energy design tool through a focus groups study in which one of the three focus groups involved were architecture students. The majority of the participants agreed that default values in function of ambition level are interesting to adapt data-input to early design, but they must be customizable and transparent. They thought that the interface and input method must be intuitive and modelling rules must be avoided. Regarding output, most preferred feedback aspects that are related to regional energy code requirements. Crawley et al. (2008) compared the features and capabilities of twenty major building energy simulation programs based on information provided by the program developers based on 14 categories. In a recent study, Attia et al. (2011) suggested a set of comprehensive selection criteria for BPS tools based on five major topics: usability and Information management of interface (UIM), Integration of Intelligent design Knowledge-Base (IIKB), accuracy of tools and ability to simulate detailed and complex building components (AASDC), Interoperability of building modelling (IBM), Integration with building design process. The results of the survey conducted in this study indicated a wide gap between architects and engineers’ priorities and tools ranking. It was found that architects prioritized the ability to create comparative reports for multiple alternatives above the input quality control and chose the ability to exchange models with 3D drawing packages such as SketchUp and 3DS Max.

In the current higher education environment in Australia, where students are struggling to balance study and work, universities are facing an increasing demand for courses with flexible delivery modes. Student expectation has changed drastically with the constantly changing technology. Academic staff endeavors to adapt online delivery modes while at the same time attempting to sustain their campus-based and face-to-face teaching approaches. This has particularly affected the selection of simulation tools and to achieve an optimum balance between various criteria has become very challenging.

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<tr>
<th>Year</th>
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<td>2010</td>
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### 3. Method

This study investigated the application of building performance simulation tools in two different master programs in two universities where the authors were involved in the design and delivery of the courses. First, the Master of Architecture (MA) program at Deakin University and second the Master of Energy Efficient and Sustainable Buildings (MEESB) program at RMIT University. The study used student feedback from surveys and continuous reflection by the teaching staff. 45 students from Deakin University and seven students from RMIT University responded to the survey. The MA programme involves design oriented architecture students where as MEESB programme includes students from various backgrounds including architecture, engineering, building science, building construction and management. The course within the MA program was delivered for six years in semester one from 2010
to 2015. The new MEESB program only commenced in 2015, hence the course under investigation was delivered only once thus far. Table 1 shows the various BPS tools used in the two programs each academic year.

4. Results and Discussions

4.1 Architecture Programme

There is a growing need for future architectural practitioners to be equipped for addressing complex problems through environmentally sustainable design by using fewer resources. However, in most schools of Architecture, there is a separation (polarization) between the “core” design studios and the “supplementary” lecture classes in technology (Oakley and Smith, 2007). Building performance simulation is a good tool for architecture students to investigate alternative design solutions during the concept development phase of a new project. Taking time away from their design endeavor to learn the software tended to impact their design process negatively. This is not a desirable outcome in a studio environment in which the emphasis is above all on authoring a good design (Charles and Thomas, 2009).

In a design centred curriculum, students’ abilities to apply understanding from their technical coursework in their design work is limited and many researchers have proposed the need for a new curricular model to overcome the limitations of this division. So the main challenges that were faced by the teaching team were “How BPS tools can be taught effectively to architecture students? How do the design oriented users interact with simulation tools? Is there a tool available that can tick most of the boxes?”

The course under investigation is a core unit within the environmental stream called “Building systems and environments” which students undertake in the fourth year of their MA studies. The simulation part was only one third of the whole course extending to a period of four weeks out of the total 11 weeks in the semester. The learning outcomes include “evaluating and appraising the appropriate selection of environmental systems to enhance thermal comfort” and “improve energy efficiency and apply computational methods and software to make informed judgments in relation to their role as built environment professionals”. When the course was delivered for the first time, students were asked to choose any existing building which may not have been constructed in the era of sustainable or energy conscious design or any of their previous year’s design studio project as the case study. However, students seemed to be disengaged with the project once their design studio kicked off. Therefore, for the subsequent years, the studio project ‘Architectural Design in Urban Contexts’ was used as the case study project.

Over the years, a number of software including Ecotect, Energy 10, Comfen and Sefaira were introduced to the students. Each software had advantages and disadvantages associated with them; the limited time period associated with the academic calendar was one of the main challenges. With its highly visual approach to building analysis and simulation, Ecotect (Marsh, 2006) seemed to be very popular among the students. However, students tend to spend too much time in building spectacularly detailed geometric models which can result in numerous potential errors or warning messages that will be very difficult to track down. Some academics feel that there is really no need to waste time having students generate their own models. Instead, a model can be given to them so that the students can concentrate on the interpretation of the results. For the students to better appreciate the benefits and limitation of the modeling tools and to better understand and interpret the results, it is important that
they get involved in the modeling and understand the relationship between the model size and running time as well as the assumptions and simplification of the model.

ENERGY-10 program automates many of the time-consuming tasks in geometry building and shortens the time required from hours or days to minutes. Building descriptions are created automatically based on defaults (Balcomb, 1997). The program facilitates quick evaluations and automates the process of both applying and ranking a variety of energy efficiency strategies. The graphical output greatly aids the process of assimilating and understanding the results. One problem reported is that some users have a difficult time going beyond the automatic model building stage as it is quite easy to get started with a shoe-box design. However, during the preliminary design stages, the user must compute wall, roof, and window areas and enter these numbers into the appropriate dialog boxes and this is seen as a barrier by the students. The access to these two tools has always been an issue as the students had to come to the university and use a machine in the computer lab which is often heavily booked for teaching purpose. As flexible delivery became part of universities strategic goals, more and more off campus students enrolled in the courses as a result of which access and licensing became problematic. As the teaching staff has to make sure there is equal opportunity for all the students enrolled in the course, a computer lab based licensing did not work as off-campus students were not required to attend the classes. As a result of the student feedback, COMFEN Program that calculates the heating and cooling energy use, and visual and thermal comfort, of commercial building facades, from the Lawrence Berkeley National Laboratory was implemented in the subsequent year. COMFEN is very simple software freely available for download, however its use was quite limited as we can model only one space with single external wall. The students had to choose one space/zone in their design that has only one wall facing outside. It took quite a while for the students to simplify their design to be modelled in the software. The flexibility and access issue was resolved. Even though, the simplicity of the geometry allowed for substantial time for the students to analyse and interpret the results, the overall perception was that “The software is not capable of modelling my whole design and one zone is not enough, I want to have windows on all the four sides.” Don et al. (2009) state that traditional simplified design tools are typically too limited to be of much use, even in conceptual design and proposed proposes an approach to the creation of design tools that address the real information needs of designers in the early stages of design of non residential buildings.

As a result of the feedback, Sefaira (2016), a cloud based software, specifically built for conceptual design was trialled in the subsequent year. Recently Sefaira released new plugins for most widely used building information management platforms such as SketchUp and Revit. After completing the course, the students were asked to complete a survey about their experience in using the software. Among the 46 students responded to the survey, 42% have used some form of BPS tools before. Majority (83%) of the students agreed that Sefaira helped them to achieve the course learning outcomes. 86% of the students felt that Sefaira helped them in better decision making with regards to their design studio project, with 20% strongly agree and 66% agree. The comments from the students mainly reflect that the software is an easy tool to understand and use and very good for early design stages. Particularly, Sefaira for SketchUp plug in helps to get immediate feedback on design decisions. The quick feedback with the real time analyser (RTA) and the ability to benchmark against the 2030 challenge was a major advantage. The 2030 challenge is global architectural challenge, issued by architecture 2030, that aims to get to carbon neutral buildings by the year 2030. Furthermore, it minimizes the number of inputs required to get meaningful results which greatly increases the ability of the architect to use the software.
Six performance metrics including energy use intensity, annual carbon emissions, spatial daylight autonomy, annual sunlight exposure, annual operating cost, peak cooling/heating load were displayed as the output. Figure 1 shows a view of the output from the RTA.

![Output from the real time analyser](image)

The main problems encountered by the students were the geometry limitation as Sefaira could only simulate a model in Sketchup which has less than 1500 planes. For detailed analysis and to control the baseline parameters further, the SketchUp model has to be uploaded in the Sefaira Web App. The SketchUp model file then must be uploaded on Sefaira’s online site in order for Web App simulation to be conducted. The building parameters for space use, zones, HVAC systems, occupancy patterns and loads were then assigned, and simulations were run. While Sefaira’s RTA plugins allows for rapid geometric design iterations and a highly visual energy analysis including daylighting visualization, with the Web App, users can gain a higher level of control over baseline parameters and the ability to utilize response curves to create strategies and bundles to further optimize the RTA geometric iterations. The Sefaira Web App also allows users to quickly compare multiple mass options against each other. Like any other applications, the running time increased with the number of planes in the geometry. In a previous study comparing actual and simulated energy between two softwares (Vasari/GB and Sefaira) energy data from Vasari/GB was significantly higher than the actual data, while modeled energy data from Sefaira is close to the actual but did not follow the same monthly energy consumption pattern as the actual data (summer loads were lower than the winter loads) (Abdullah and Cross, 2004).

The students were not satisfied with the thermal comfort analysis in Sefaira. The thermal comfort analysis seemed less advanced; the output was in the form of number of occupied hours for temperatures between 18°C to 28°C (see Figure 2) instead of the conventional PMV/PPD plots displayed by other tools such as Ecotect. Students expect to have thermal comfort outputs displayed for various seasons rather than aggregated annually. As noted by Weytjens et al (2012), line-graphs and histograms are not preferred mode of output among architects for design feedback. Students also found the Web App confusing as it seemed it required them to upload the model after every small change they make on the model. Some suspected this is because of certain bugs in the software. This year Sefaira swapped Fulcrum engine with industry standard EnergyPlus in its new "SYSTEMS" product and hopefully the bugs
will be eliminated. Similar to other softwares, the students found there was not enough time to learn the software and required more tutorial classes.

![Figure 2: Thermal comfort output](image)

The tool “Sefaira” seem to be addressing most of the current challenges faced by the students as well as academic staff involved in teaching large classes. The purpose of Sefaira was to get quick results with minimum number of inputs and compare the general impact of different strategies rather than to get the scale of details achieved by compliance models. An advantage of Sefaira was that it is a plug-in of Sketchup and Sketchup is already used widely by architects in the early phase of the design process.

### 4.2. MEESB Programme

The MEESB program is a new specialised master program developed by the School of Property, Construction and Project Management at RMIT University. The program is developed with close industry input as a result of the need identified in training graduates with expertise and capability in analysing and evaluating energy efficiency in the building sector. The course that was investigated is ‘Building modelling and simulation’ a second year core subject for the master program. The course is designed and delivered as a ‘blended mode’ course in which one-third of the content is delivered face-to-face through workshops and the rest is delivered online. The course aims to develop specialised skills and knowledge required to carry out complex simulation and modelling tasks, developing professional capabilities in multiple modelling platforms including thermal, energy, air flow and lighting simulation. The course teaches students the importance of validating the quality performance of a building simulation tool through the BESTEST (Building Energy Simulation Test) method and the introduction of both residential and commercial building simulation tools commonly used in Australia.

A regulatory building simulation tool for residential, FirstRate 5, was introduced to students to understand the important parameters that govern the performance of residential buildings in Australia. FirstRate 5 is a residential thermal performance assessment software used to rate the energy efficiency compliance of residential buildings to the minimum 6-star standard under the National Construction Code of Australia (NCC). The NCC standard applies to all new homes and major renovations and extensions carried out in Australia. The software tool generates ratings based on the NatHERS...
(Nationwide House Energy Rating Scheme) star rating system on a 0-10 star scale for homes. In addition, a commercial whole building simulation tool, IESVE (Integrated Environmental Solutions Virtual Environment), was used to develop students’ understanding and expertise in building modelling and delivery of sustainable buildings. IESVE is a building energy analysis and performance modelling software which could be used to test various design options and help to identify sustainable building solutions through in-depth analysis on energy use, CO₂ emissions, occupant comfort, light levels and airflow impacted by different building constructions. Figures 3 and 4 show the view of a model and the occupancy schedule in IESVE. Students purchased their own standalone license for a reasonable price and installed the software in their PC which gave them enough flexibility to work off campus.
The feedback from the first cohort of students in the course was mainly positive. Students found that the learning curve for FirstRate5 is manageable but required much effort in mastering the IESVE software, which is expected as IESVE is a much more complex software in terms of its capabilities and inputs requirement. Online tutorials were provided to the students to learn the software on their own time before the actual assessments commenced. Students found the online tutorials and materials provided are of great help in their understanding and learning of the software. For IESVE, students will need to incorporate appropriate building design requirement such as heating and cooling settings, usage profiles, lighting usage, internal heat gains, etc. These requirements are closely linked to regulations and standards which students will need to understand the codes and practices governing certain types of building design besides learning how to model using the software. Most of the students have experienced using some kind of simulation tool such as EnergyPlus before taking this course. They found that the IESVE software provides good user interface, ease to use and certain degree of accuracy in building modelling. Students are happy with the capabilities of IESVE in terms of the versatility of results generations and agreed that the software helped to achieve the learning outcomes of the course. The software also helped students better understand the expectations of the related profession such as ESD industry. Even though the tool can be used to understand the parameters in relation to building performance, for in depth understanding of some of the complex relationships between parameters, one should spend substantial amount of time exploring the tool. Students think that the weather files provided in the software could be more comprehensive in covering more regions in order to provide more accurate simulation results. The capability of the software in accepting and exchanging different CAD drawings and models will also need to be improved.

5. Conclusions

The application of building modelling using computer simulation tools plays an integral role in the design and evaluation of energy efficient and sustainable buildings. Architects, engineering and construction management professionals use building simulation to understand and assess building performance. The results of building modelling and simulation are required at multiple stages of the design process and need to be evaluated, critiqued and communicated to multiple stakeholders, including clients, architects, engineers and regulatory bodies in order to deliver a sustainable building outcome.

Selecting an ideal tool for building performance evaluation is challenging for environmental design. The two cohorts of students investigated in this study had considerably different expectations regarding the use of simulation tools and this is quite similar to how the building industry actually operates. For architecture students, creating the geometry closely resembling their design was very important. They prioritized the ability to exchange models with 3D drawing packages and preferred fast performance feedback that is fully integrated into their design environments. The flexible delivery, which is often overlooked in architecture, was highly desirable for students who have competing time demands and are struggling to balance study and work. Recently developed cloud based tools such as Sefaira were well suited for flexible off campus delivery, however the accuracy and reliability of the simulation engine need improvement. For the specialist master program, established tools such as IESVE provided a good platform for whole building performance analysis. The delivery of this building modelling and simulation course could be further enhanced and improved by introducing more hands on sessions to help students to get a deeper understanding of the use and capabilities of the software. Industry experts could be invited to present the practical experiences and implementations of the software in real life situation to the students. These improvements to the course will certainly help to expand the horizon of application.
of building simulation tools in the industry and better equip students to gain professional employment in the future.

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