Understanding the differences of integrating building performance simulation in the architectural education system

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Abstract

In order to assist tertiary architectural education institutions as well as the architecture profession in developing course material and training packages related to Building Performance Simulation (BPS), we present the outcome of a survey conducted in Australia, India, the US and the UK. The main objective of the survey was to investigate how BPS is taught at a number of different architecture schools at universities in these countries and to point out potential difficulties and barriers. Based on the survey, the paper proposes a number of recommendations and highlights opportunities for future degree schemes that develop module content and learning objectives/ outcome for teaching BPS at architectural tertiary educational institutions.

Introduction

In an earlier paper (Soebarto et al., 2015) we pointed out that despite the fact that significant effort has been directed at making building performance simulation (BPS) inherent in architectural practice, anecdotal evidence showed that there is still a long way before this goal will be achieved. We also showed (by conducting a survey) that a large number of architects (74%) surveyed did not use BPS in their day-to-day practice. At the same time 87% respondents expressed a strong desire to embrace BPS. Based on these results, the paper proposed a number of recommendations to overcome the challenge of applying BPS in the mainstream architectural practices, in line with IBPSA's vision (Clarke, 2015) on bridging the gap between research and practice.

Three main suggestions were proposed by the architects that participated in this survey, one of which was to make building performance analysis a compulsory subject in tertiary education of architecture. This is an interesting point as many schools teaching architecture claim to already embed the use of BPS in the module specification and teaching.

An important component in the educational process of architecture at university level is the architecture design studio. In the design studio, students receive hands-on instruction in architectural design. As the architectural studio forms one of the most important components in the degree of becoming an architect, one could claim that a reason for BPS not successfully being applied in the design process has to do with the fact that it is not embedded in such studio teaching. However, previous research suggests the opposite and demonstrates approaches on how simulation is effectively integrated in some design studio teaching, for example, Soebarto (2005); Charles and Thomas (2010; Charles and Thomas (2009); Delbin et al (2006).

This paper aims to shed some light on this ambiguity and investigates how BPS is taught at some of the most prestigious schools of architecture in Australia, US, India and the UK.

Further to that, it is hoped that the results will help to develop new course material for new architecture programs around the world including a new Architecture degree at Loughborough University.

Methodology

The investigation presented in this paper was based on an online survey to a number of schools teaching BPS in four countries: Australia, the US, India and the UK. The invitations to participate in the survey were distributed to local tertiary architecture educational institutions and through direct contacts. Note that it was a requirement for the study to survey those who teach BPS to architectural rather than engineering students to capture the sole experience and perspective of this particular domain.

We investigated for example the type of simulation taught (thermal airflow, daylighting, other), at what level and in what context BPS was integrated in academic teaching, and the amount of time spent on teaching a particular subject. There were 36 questions in total, some of which were multiple-choice, some require short answers. The respondent could also add additional information. The results were analysed based on country, background (e.g. architecture, civil engineering) and year level (undergraduate or postgraduate), using frequency analysis as well as an exploratory approach. The survey questions are presented in Table 1.

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Table 1
Summary of questionnaire (highlighted questions were optional)

	Demography/ General
1	General information, optional (name, university and contact details)
2	Educational background (Architect, Civil Engineer, Mechanical Engineer, other)
3	Country
4	Years of experience in teaching BPS (< 5; 5 < yrs < 10; 10 < yrs < 20; >20)
5	Member of IBPSA (yes/no)
6	Type of school/ discipline (Architecture, Mechanical Engineering, Civil Engineering, other)
	Teaching (architectural or engineering students)
7	Level/ year of architectural students (undergraduates, postgraduates, both)
8	Year in which BPS is taught to undergraduate students
9	Background of students prior to be enrolled on BPS
10	Size of each class (< 10;10-30; 31-50; >50) – multiple selections possible
11	If >50, are classes divided into smaller groups in terms of learning BPS?
12	Number of semesters that BPS is part of the curriculum
13	Number of hours that are spend on teaching BPS per semester (undergraduate and postgraduate).
14	Method of teaching (face-to-face, including online teaching, online tutorials, other)
15	Percentage of time spent on theory, applications and analysis
16	Percentage of how much is design driven or case study driven
17	Is it compulsory or elective
18	Format of the course– is it part of design studio, a separate course but supports design studio, or totally an independent course
19	Student group or individual work , or both
20	Area of building performance simulation (airflow, thermal, daylight, hygrothermal, acoustics, structures, others) - multiple selections possible
21	What software is used (e.g. DesignBuilder, IES VE, Ecotect, Sefaira, Insight 360/ Revit, DOE-2, VisualDOE, Radiance, DaySIM, 3D Max, Ladybug, OpenStudio, AECOsim, Other) - multiple selections possible
22	Reason(s) for using those software programs
23	Type of textbook/resources used by the teachers
	Design Studio (Architects)
24	Role of design studio in teaching BPS (descriptive)
25	Types of projects mostly dealt with (e.g. residential, hotel, office, educational, health care, other) - multiple selections possible
26	Types of design analysis (e.g. shading, energy, daylighting, airflow, other) - multiple selections possible
27	The tasks spent with the most time (e.g. planning, meeting, design, simulation, analysis, presentation) - ranking according to time
28	Design and documentation tools used in the process (e.g. hand drawing, rules of thumb, physical models, CAD, BIM, others)- multiple selections possible
	Analysis and Feedback
29	How the analyses is mostly conducted (e.g. in relation to rules of thumb, design guidelines, by using internal programme analysis tools) - multiple selections possible
30	Analysis of results and outputs (e.g. individual, group effort, interdisciplinary)
31	Summarize feedback that is provided by students based on teaching BPS
32	Describe issues/ complaints about tools if any (e.g. user friendliness of the interface, difficulty in modelling complex forms, can't easily use the CAD models, simulation time, can't easily interpret results, others) - multiple selections possible
33	Level of satisfaction with the software (from very satisfied to very dissatisfied)
34	Do students see the value or benefits in learning BPS
	Expectations and Recommendations
35	Suggest future ways to incorporate building performance assessments in teaching to Architects
36	Any other comments

Results and Discussion

General

Out of 60 architecture schools and individuals invited to the survey, we received 49 responses with 16 from the US (32.6%), 12 from the UK (24.5%), 9 from Australia (18.4%), 5 from India (10.2%), and others (14.3%). We included those who came from 'others' because they resided in one of the above countries but also taught in other countries, including Canada, Portugal, Turkey, Israel and Singapore. In general, we were not trying to receive as many as possible responses but targeted tertiary institutions known to teach BPS.

Out of these 49 responses, the majority (32.65%) had between 5 and 10 years of experience of teaching BPS, while there were 26.5% with between 10 and 20 years and 22.4% with more than 20 years of experience. That means that more than 80% of all respondents could demonstrate significant experience in the bespoke field.

In terms of the educational background, more than half of the respondents were coming from an architectural background (63%), with only 6.1% having a degree in civil engineering, 10.2% in mechanical engineering, and 20.7% 'others', that is from multiple different fields such as electrical engineering, physics and astronomy, mathematics, building services, and construction management. The focus of the survey was to understand how BPS is taught to architectural students, so not surprisingly, 84% of all respondents answered to solely teach to architectural students.

On average the respondents taught BPS more to postgraduates (50%) rather than undergraduates (13.2%) or both degree schemes (36.8%). The students had a variety of background knowledge in courses such as building energy, energy and environment, environmental systems etc.

The class size varied with the most universities teaching to class sizes of 10-30 (44.8%) or class sizes of more than 50 (42.1%) and only few teaching to less than 10 (7.9%) or between 31 and 50 (13.2%). If taught to class sizes of above 50 students, in almost 40% of the time the classes were not divided into smaller group, i.e. BPS is then taught to large groups of students with low staff to student ratio.

India, Australia and the US demonstrate cases where BPS is taught three (in one case up to four) semesters as part of the architecture curriculum. The majority of the other universities however teach BPS only one (55%) or two semesters (33%).

On average 19 teaching hours were spent per semester at the undergraduate level and 27 hours at the postgraduate level. The methods of teaching are shown in Figure 1. The majority of academics (97%) use face to face as their main teaching method, which included lectures and supervised workshops.

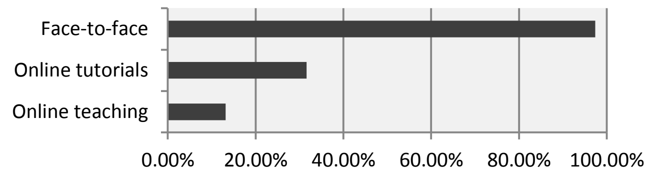

Figure 1: Teaching methods used in both postgraduate and undergraduate teaching (in %) – multiple selections were possible.

Overall, there is great variety shown of the amount of time spent on theory, application and analysis. The average times (in %) are shown in Figure 2, however the individual's responses differed and interestingly, there was no correlation with respect to the educational background of the lecturer vs the level of theory, application or analysis applied in teaching the subject.

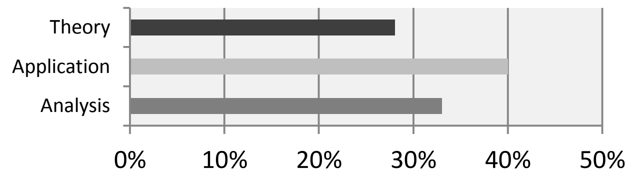

Figure 2: Amount of time (in %) spent on average on theory, application and analysis of all lecturers.

This is demonstrated in Figure 3 that summarizes all academics with either a civil or a mechanical engineering background (6 academics out of 49 respondents). The amount of theory that is taught on the overall module varied from less than 10% to up to 60%. The results also reveal one academic with an architectural background teaching BPS by focussing 80% on theory, 20% on the analysis and 0% on the application.

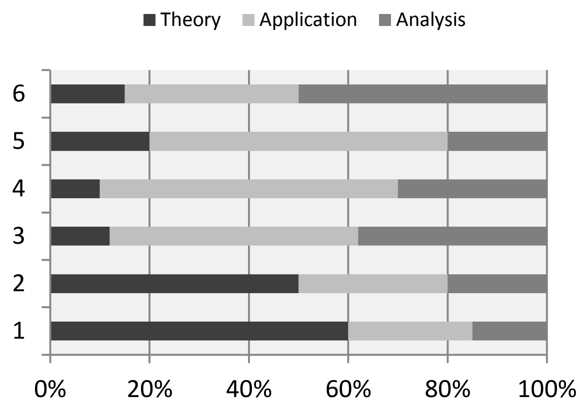

Figure 3: Amount of time (in %) spent on theory, application and analysis of six academics with an engineering educational background teaching to architectural students.

The BPS specific fields of teaching differ with the majority of faculties or schools focussing on thermal (97%), daylight (74%) and airflow (45%) simulation.

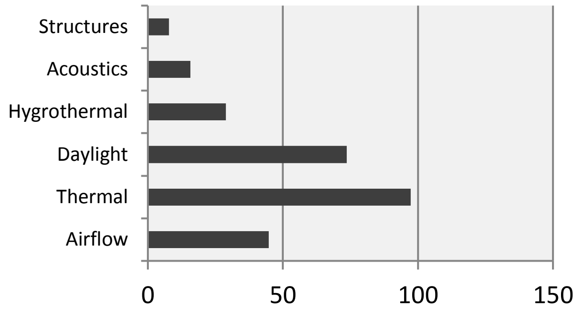

Figure 4: Area of BPS taught (in %).

The selection of tools that lectures chose in their teaching is listed in Figure 5. As can be seen, majority of the tools used were DesignBuilder and IESVE. Radiance and Ecotect were also widely used.

Comments were made that the choice of tool depended on "its accuracy, flexibility, thorough documentation, and transparent calculations." Some also suggested that the tool was chosen for its options on "geometry inputs" or graphical user interface (GUI) or for being a GUI for a particular tool such as EnergyPlus or Radiance "that reads native IDF, which allows (..) to customize the IDF flexibly using the IDF Editor."

Few respondents commented on the ability of a tool to offer design exploration and parametric design, i.e. the possibility for students that "primarily want to explore the impact of architectural decisions, such as building geometry and envelope design." Some tools are shown to allow students to focus on these decisions while linking to validated simulation engines, such as DesignBuilder and DIVA.

For the majority of the respondents, the choice for these is reported to depend on the following:

- availability of specific software at the university,
- previous expertise of the lecturer in a certain tool and/or personal familiarity,
- whether the software is open source and/ or free of charge,
- compatibility with other CAD software, such as Sketch up and Revit,
- that the tool is validated,
- that the tool provides a user-friendly interface,
- whether the tool is commercially used/ accepted

When it comes to the application of BPS and the use of the tools, more than half (52.6%) stated that the students would work both, individually and in groups, whilst only 15.8% work in groups and the remaining 31.6% work on an individual base.

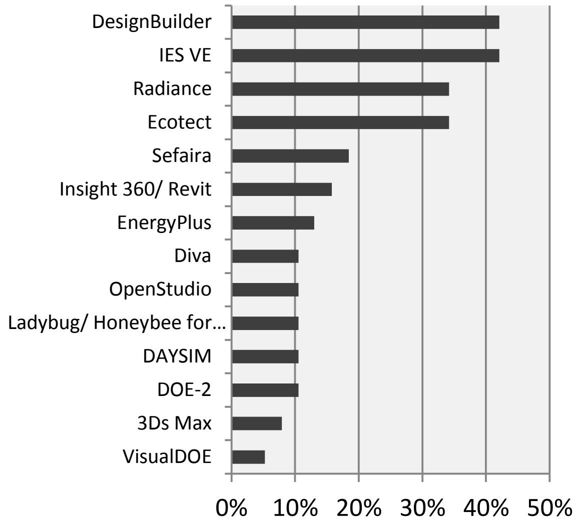

Figure 5: Software programmes most commonly used (in %).

The type of analysis conducted in the module is consistent with the specific field of teaching, with the analysis focussing mostly on energy (94.12%), daylighting (79.41%), shading (73.53%), and airflow (26.47%). Few respondents mentioned urban energy networks, acoustics, climate analysis, glazing and thermal comfort, and building envelope performance.

Almost 50% of the respondents stated that teaching BPS to architectural students was compulsory. This means that for the other 50%, despite BPS being embedded in the module specifications and teaching curriculum, the students can still opt out.

Design Studio

We wanted to understand how widespread the use of design studio is when teaching BPS to architectural students.

In order to do so, we first asked about the use of case study based teaching in general. The results show that this was quite high in percentage: 72% of all respondents agreed that their teaching would be at least 50% case study focussed, with almost half of them (i.e. 47%) stating that it was entirely (i.e. 100%) case study focussed.

The type of case studies mostly used were office (80.56%), residential (72.22%), educational (52.78%), health care buildings (16.67%), and hotels (11.11%); also mentioned were museums and libraries, as well as mixed-use residential buildings.

Contrary to the case study based teaching approach, however, only a very small percentage (8%) stated that they were using design studio as a means of teaching BPS; it appeared that often BPS is taught in parallel to studio teaching but with no connection or interface between the two. Understanding the tasks and methods or tools used in BPS centred studio teaching, led to the overviews presented in Figure 6 and 7.

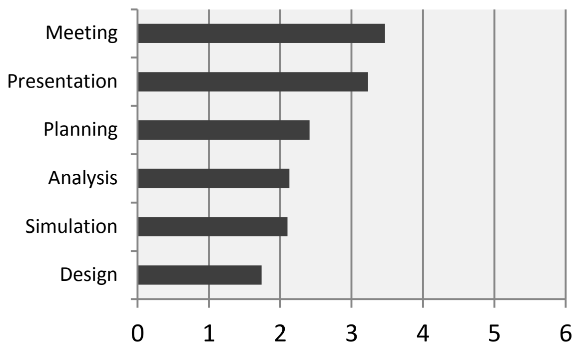

Figure 6: Tasks spent most time with (on a rating scale of 1-6, where 1 is 'spent least time' is and 6 is 'spent most time').

Comparing Figure 2 with Figure 6, one can see that the focus in studio teaching shifts to the design. More and significant time is spent on tasks such as planning, meetings, and presentations.

Consequently, the use of tools shifts towards tools that support the design, the planning and the presentation. Figure 7 shows the tools that were mostly used in design studio teaching. Physical models were only on fourth position behind CAD tools, methods of rules of thumb and hand drawings.

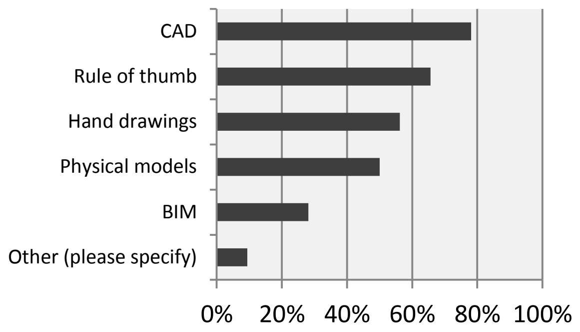

Figure 7: Design and documentation tools used in the process of studio teaching (in %).

The relationship between the design studio and teaching BPS

Design studio was described by the interviewees as a “design decision tool” and an “exploration of design options” that offers “complete integration” for “enrichment learning”. It helps in “understanding of basic building science that is fundamental to understand the results of simulation and its parameters for the analysis of building performance.” Some interviewees described it as “a series of case study exercises.”

We asked interviewees what they think about the relationship between design studio and teaching BPS. The answers from 37 of them showed a large variety with respondents describing the role of BPS as:

- Increasing students’ intuition: “BPS increases intuition that can drive design decisions in studio.” The effect of this was seen to some as similar as conducting a climate analysis.
- Improving the ability of tackling and evaluating a specific problem: “The role of BPS is to help students structure their design problem and adequately select and use simulation methods for evaluation.”
- Improving the decision making process: “BPS will help students understand the impact of their design on indoor thermal comfort, energy use, daylight in the spaces, etc. and to make informed decisions in developing their design project.”; “BPS can inform the design decisions. Students become more aware of the implications of certain design decisions in terms of building performance. “
- Enhancing design exploration: “BPS can help students explore their design better by understanding the consequences of design decisions on future performance of the building/design.”

The relationship between BPS and the studio teaching was expressed in a number of different ways:

1. There was no direct relationship

One respondent commented that architectural students were not interested in the use of simulation and that for that reason the use of BPS was not part of the design curriculum.

2. There was an indirect relationship

The use of BPS could have an indirect impact, i.e. even if there was no direct link to studios. That was for example, if the use of BPS was not a requirement and taught on a separate course. “I see a large portion of students performing analysis on their studio projects especially the quarter they take the course.” Alternatively, this can have a further (indirect) impact by students deciding to use BPS on their dissertation projects: “students have the option to use a studio project as the basis for their final project.”

3. There was a direct relationship

This was the case if BPS was fully integrated within the architecture studio. For example, there was a “BPS expert faculty as a part of the design studio team to ensure that all students run their design through a BPS route before freezing the design.”

All respondents who answered to this question mentioned advantages and challenges to using studio teaching as a means of learning BPS. Reported challenges ranged from comments such as “difficult” to BPS having only a limited impact.

Overall, the integration within design studio was seen as “difficult and frustrating.” Some stated that it was “difficult at first, particularly in its integration with design studio, but much more successful once the basic principles behind environmental forces are fully understood"

Logistical problems were mentioned as well: "It is very difficult to teach BPS concurrently with design studio because you need a design in order to analyse it. Typically, studios do not start producing designs until 3-4 weeks into a semester (sometimes later), and they are usually not specific enough to be interesting in the context of BPS. In many of these cases, the analysis is therefore generic and there was no need to link the BPS to the studio in the first place. "

Many respondents however saw positive aspects in studio teaching and described it as a teaching method that would "work best if BPS is integrated" fully within design studio". Throughout the term, and starting from the initial site analysis, following every step of the design process, the "students should feel encouraged to use BPS tools as support tools". Based on the concept of the design studio teaching, the choice and necessary level of detail on the use of BPS was perceived as variable.

Often respondents reported that BPS was separated from studio and that students learnt the simulation in one module (e.g. daylight simulation) and then applied the knowledge in their architecture studio (i.e., an indirect relationship).

In Bleil De Souza (2013) BPS and studio teaching were taught in separation. It was up to the postgraduate architectural students to apply BPS to their design studio.

For another MSc programme offered to architectural students, students had to use the environmental analysis as the means to support or generate design ideas as part of a design studio.

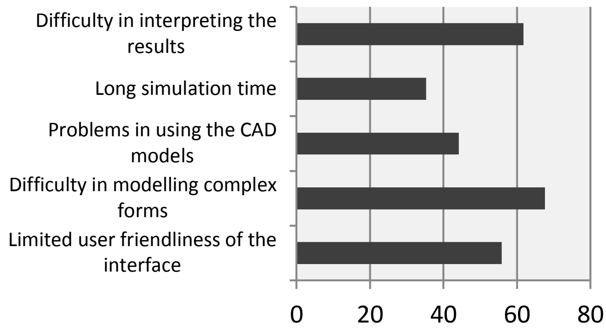

Figure 8: Difficulties or complaints mentioned by students when using BPS (in %)

Problems faced

When asked to comment about the problems of teaching BPS to architectural students, many commented on the difference between architectural and engineering students (in general) first.

For example, interviewees reported that architectural students had a lower tolerance for non-intuitive graphic user interfaces. They saw the benefit of studio teaching and the values of BPS but they were "annoyed if the user interface is too complicated". Opposed to that, engineering students could see the benefit of BPS easier and were "less affected" by the user interface.

It was also pointed out that architecture students had difficulties in understanding BPS. "Really what they joined the course for - only to find out that it is too technical and not as enjoyable as design". Most common difficulties and complaints (that were collected at the end of the year's student feedback) are summarized in Figure 8.

Interestingly, based on end of the term student surveys, the user friendliness and the simulation time were not mentioned as the main problems; however, the difficulty in interpreting the results, i.e. the analysis, was what caused the biggest problems to students.

From the lecturer's perspective, having too much faith into the software was one of the main concerns, i.e. that "generally the students seem to like the tools, but believe too much in the absolute accuracy of the results" or that "they are in control of the program" and that they only "want to be given specific numerical targets to achieve."

Future suggestions

Interviewees proposed a number of different ideas for future integration such as

- To offer additional (non-BPS related) support such as "manuals together with theory and software guidance."
- To differentiate between basic and advanced level of BPS teaching as per proficiency, for example 'basic' as to allow conceptual design support and 'advanced' as to understand the underlying physical principles in using BPS. (Beausoleil-Morrison and Hopfe, 2016b)
- To increase the amount of analysis in order to make BPS results easier to understand. It is argued that if BPS is incorporated into the architectural narrative or the discourse, architecture students will be more interested to use simulation for representation and analysis in their designs.
- To develop new metrics, including "simple metrics and indicators that correlate well with detailed computer simulations for various building typologies", e.g. daylight factors, daylight autonomy (DA) or useful daylight illuminance (UDI).

Some interviewees suggested to start earlier and to distinguish between undergraduate (UG) and postgraduate (PG) teaching, e.g. "BPS software should be introduced at UG level for basic understanding. More complex models and building physics can be performed at PG level". "BPS learning would be more desirable if available in earlier so that (students) can practice in more design studios."

Other respondents suggested using BPS in parallel of CAD training, e.g. "in the background of building CAD software showing results as the design evolves", but "it should not be a separate track of endeavour."

Three interviewees commented on the knowledge base and suggested to increase the amount of theory:

- To "make it part of design exploration in combination with other methods such as observation, calculation, direct measurement and physical modelling"
- To "include high school physics and chemistry (applied) from first year itself."
- To "start introducing them to the basics from first year on."
- To "provide solid foundation on the fundamentals (first principles) for clear analysis of results."

Better integration with other degrees is seen as a potential solution, for example "collaboration with local architecture and engineering firms with real projects" or within "research studios, where students are encouraged to experiment with BPS tools as part of design decision making."

Many perceived the greater integration within studio teaching as the future of teaching BPS to architectural students. Several interviewees commented positively about integrating BPS within studio teaching by stating that there should be "more project based simulation"; "more integrated in the design studios and part of the final submission."; "more hand on sessions and more time spent to analyse and interpret the results".

One interviewee suggested to "run a design studio and design brief with the intention of being informed by preliminary simulation analysis." Then "provide this general information to an entire class for them to use and consider in their design project. "

Conclusions

The results showed that there was no single mode of teaching BPS in architecture schools, even within the same country. Some schools taught BPS as part of compulsory courses and others offered it as an elective subject. Some focussed on a certain area such as thermal or daylighting simulation only, while others focus on whole- building simulation.

In some cases there was a clear difference in the approach by which BPS was taught in architecture schools as opposed to engineering (e.g. an increased use of case studies) (as reported for example in Beausoleil-Morrison and Hopfe, 2016a).

Many respondents described their strategy as a series of case studies when teaching to architectural students.

The method that was unique when teaching at schools of architecture compared to engineering students was the design studio teaching; however, the results also demonstrate the amount of difficulties and problems this concept could introduce.

Soebarto (2005) mentioned three issues when trialling a design studio in order to teach BPS, as follows:

1. Students need sufficient knowledge to understand the basic principles
2. Architectural students do not necessarily put environmental concerns first, that includes energy consumption, thermal comfort, and others.
3. Current BPS tools are not easy to use.

Delbin et al (2006) also mentioned the challenge of teaching BPS as part of the design studio and concluded that it was not easy to introduce building simulation programs to architecture students. In order to be successful, the students must have a prior knowledge related to the basic principles of the simulation.

Opposed to that Charles and Thomas (2010) advocated for less theory and more application and analysis as it is "to educate a consumer of BPS instead of preparing a producer of simulation."

With this survey, it was found that architecture students would see the value of BPS when it was part of their design projects but that they required additional support with respect to the interpretation of results.

In addition, the capability of BPS tools to model complex forms and their user-friendliness were the two factors demanded by architecture students while a very complex BPS tool discouraged them to use it. These factors may indicate the reasons for our earlier finding, that during the design process architects often prefer to use other approaches instead of BPS (e.g. rules of thumb, environmental design guides) (Soebarto et al., 2015).

The acceptance of BPS tools from student perspective has changed significantly in the past 10 years, but it is always a challenge to make sure that they can match the skills needed to use the available tools with the underlying knowledge and expertise to use them in a responsible manner.

The results of this survey are encouraging in the way that they indicated there is room for improvement. A shift in thinking in the architecture academia will be necessary. To engage aspiring architects earlier in interdisciplinary student work involving BPS might be a way forward in the future. In order to introduce BPS in studio teaching more, one will need to persuade studio teachers of the importance of teaching building physics together with construction. One interviewee suggested to "integrate physics and construction as much as possible and try to sell them a 'package'". It will not be guaranteed that students will agree with it but they will have "a hard time to argue against it". Much of future education of BPS will depend on communication processes as cross-disciplinary education is key for the success.

Acknowledgement

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