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A MULTI-DISCIPLINARY, CONSULTANCY-BASED TEACHING MODEL: POTENTIALS AND LIMITATIONS

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ABSTRACT

The paper is a reflection on the content and delivery method of an introductory building performance simulation (BPS) course. In this case it is the only exposure to BPS a student (architecture or engineering) will receive while at school. The authors examine the outcome of a multidisciplinary teaching setup that instituted a designer-consultant-like collaboration between an architecture design studio and a course with both BPS and data acquisition (DA) content. Participants' surveys are analyzed to cast light on the potentials and limitations of this consultancy-based teaching model. The authors also speculate on two potential roles within architecture offices for these graduates who know just the basics of building simulation: the role of BPS consumer and the role of triage-ist, both defined in the following.

INTRODUCTION

BPS tools can be very powerful learning tools that help students become better aware of issues such as energy in buildings (Strand and Fisher, 2000). A growing number of architecture students are exposed to building performance simulation BPS while at school. While a positive trend, much is left to be done to reach more students and to more seamlessly integrate BPS throughout the curriculum (including within design studios). Along with scores of fellow educators in architecture, we regret that BPS content is often relegated to an elective status. In general student will only have the opportunity to take one semester of BPS during their formal education, thus it is critical that we, as educators, ask ourselves what and how to present BPS. The validity of this question is underscored by the difficulty for students to model accurately as shown in Ibarra and Reinhart (2009).

As a response to the current limited footprint of integrated BPS at our University, we have proposed and run a consultancy-based undergraduate teaching setup involving a multidisciplinary course whose students consult with an architectural design studio's students on a design problem. The elective three credit-hour course was attended by a group of 14 architecture and engineering students and jointly taught by the authors, an architect and an engineer, with the former also instructing the associated studio. The course mixed BPS and data acquisition (DA) content. This paper analyzes the outcome of this teaching setup. It complements the presentation of this teaching setup's design in (Charles and Thomas, 2009). Some of the work produced collaboratively is presented and the students' responses to a survey are analyzed.

With a background in architecture practice, we also ask ourselves the question of the role graduates of our consultancy-based teaching setup could play at architecture practices. We posit that such graduates equipped with notion (as we, arguably, give them) of BPS, DA and designer-consultant collaboration can play valuable roles within architecture firms at the interface between BPS and architectural design. In this paper, we will begin to delineate two possible roles for such non-specialists in BPS: the consumer and the triage-ist.

LITERATURE REVIEW

How does our teaching multidisciplinary, consultancy-based, and design-based setup compare and contrast with other approaches to teaching BPS and/with studio?

"Learning BPS in studio." Unlike studios in which the designers are taught BPS tools and use the tools themselves on their own design (Soebarto, 2005), in our setup, the studio students do not learn or use BPS tools themselves. Our setup mimics the case often found in practice in which the designer receives a feedback from a BPS analysis prepared by the building modeling expert.

"Consultancy-based BPS Course-Studio linkage." and "role-playing." In terms of the collaboration between the BPS+DA course and the architecture studio, our joint setup resembles the teaching methods in which architecture students and engineering students play their respective professional roles of designers and consulting engineers (Derome, D. et al. 2004). In our BPS course however, both populations are involved in building modeling.

"Augmented BPS." Our joint setup borrows from the approaches of teaching *bona fide* BPS modellers (Jensen, 2004) but balances the student's building modelling learning with other learning activities such as design investigation, DA and other forms of measuring with hand-held devices as a means to ground the BPS in experiential and sensorial knowing. The latter point shares much in common with Strand and Fisher's (2000) use of BPS tools to develop the student's thermal intuition.

"Post Occupancy Assessment." The documentation and modeling of an occupied building in our BPS+DA course shares many aspects in common with the Vital Signs project (Degelman and Soebarto, 1996). However, our setup subsequently integrates a collaborative design component.

BPS+DA COURSE AND STUDIO: FROM SEPARATE TO COLLABORATIVE

As described in greater detail in (PC & CT, 2009), the collaboration between the BPS+DA course and the studio only occurred during the last five weeks of the semester. Prior to that, the studio worked on two separate projects concerned with advanced issues in building envelope design. During the same initial ten weeks of the semester, eight of the 14 students in the BPS+DA course learned BPS while the remaining six leaned DA.

The BPS+DA course objectives were outlined in the syllabus as follow ("BPS" or "DA" in parenthesis indicates an objective pertaining specifically to one area):

a-1: operate successfully in a **collaboration** between architects and engineers;
a-2: be familiar with the concept of **thermal comfort** in buildings;
a-3: describe on a **basic** level the **physics** of energy transfer in a building;
b-1: **use a simple BPS model** of a single room (BPS);
b-2: be familiar with the **basics of DA** (DA);
b-3: **interpret the output** of a model (BPS) ;
b-4: **interpret** results of a **measurement** (DA);
c-1: **create a more complicated BPS model** (BPS);
c-2: design and implement an apparatus to **collect comfort/climate data** over a long period of time (DA);
d-1: **use BPS to guide the design** of a space; (BPS)

Objectives (a-1-3) aimed at bridging the gap between architects' and engineers' ways of thinking as well as grounding the BPS as described in the "augmented BPS" bullet in the previous section. Objectives (….) aim at providing the student with basic conceptual as well as applied/hands-on knowledge in BPS or in DA. Objectives (b-3) and (b-4) emphasize the importance of the correct interpretation of measured data or modelling result. Objectives (c-1) through (d-1) are separate because they are more advanced and more difficult to achieve. Objective (d-1) acts as a capstone that bridges analysis and design. The list of objectives explicitly distinguishes between the ability to "use a simple BPS model" and the ability to "create a more complicated model" to reinforce the idea in the student that a lot can be learned from the iterative use of a simple, one-zone model tested under varying "what ifs" configurations.

Analysis and Building Modeling

The assignments in the BPS+DA course required the students to collect data, survey and document an existing student housing building on our campus (figure 1). The data collected included four temperature and one relative humidity measurement acquired through a LABview (National Instruments) setup installed in the room occupied by a student in the course as well as weather data using a packaged weather station.

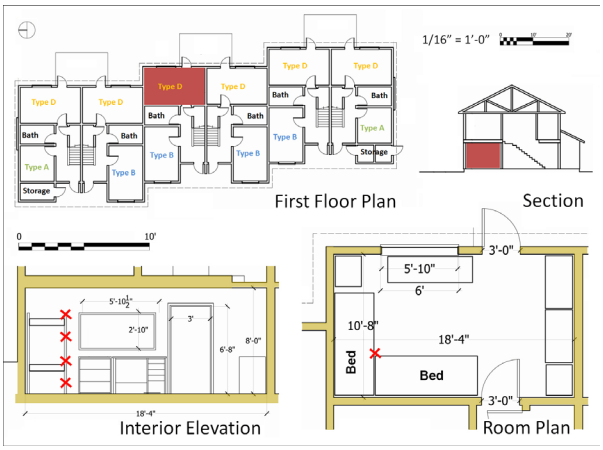

Figure 1: A page documenting the general layout of student housing building and the occupied room in which a data acquisition system was installed (4 Thermocouples are positioned along the height of a bunk bed post).

Students in the BPS+DA who "specialized" in BPS first created one transient thermal energy model with TRNSYS 16 (Klein, 2000) and one bulk air flow model CONTAM 2.4c (Dols and Walton, 2002) of the occupied room and three adjacent spaces. Then, using common base models, each BPS student ran a few "what if" scenarios to evaluate the impact of different parameters such as infiltration rates, outside wall insulation level, configuration of sun shading, accounting for cold bridges, and slab on grade models, to name a few. Some students also used CpGen, a wind pressure coefficient generator (Knoll et al., 1997), THERM 5.2, a 2-D conduction and radiation heat-transfer analysis tool (Mitchell et al., 2006), or two climate analysis tools.

As the culminating point of this initial ten-week period, the students in the BPS+DA course presented their analysis work on the student housing building to the studio students during a three-hour briefing session.

Studio objectives

Throughout its three successive design problems, the overarching learning objective of the advanced undergraduate studio was for students to gain an understanding of envelopes in building. In addition, in the third design problem –the upgrade/retrofit of the existing student housing—, the objective was to learn to work collaboratively with the consultants from the BPS+DA course and to incorporate insights brought by building modeling in the design process.

THE CONSULTANCY BETWEEN THE COURSE AND THE STUDIO

The already mentioned briefing session at week ten marked the starting point of the work on the student housing retrofit project in the studio. It was also at this time that the collaboration between the studio and the students in the BPS+DA course began. Six multidisciplinary teams were formed, each composed of two studio students, one BPS-trained student and one DA-trained student. The members of the teams worked together for the remainder—five weeks— of the semester. First, each team were tasked with outlining a building concept (Figure 2): describing the team's framing of the problem at hand and design intentions. Each team's progress toward defining a building concept was monitored both through presentations and discussion/question sessions during the BPS+DA course and the design studio meeting class times. During these sessions, the interest and feasibility of modeling particular issue/"what if's" pertaining to a specific building concept were discussed, Potential DA investigations were similarly discussed.

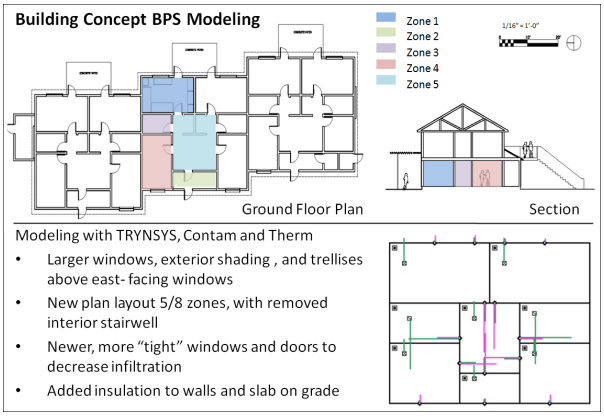

Figure 2: A building concept page listing BPS modelling intent. The plan diagram on the lower right is a Contam model showing the horizontally adjacent units joined together as well as mass flow rate at openings, supply and return registers.

Design-based Building Modeling and More

Following the framing of a team's building concept, the BPS and DA students began to investigate their ideas concurrently with the development of the design by the team of studio students. The BPS modelling workflow consisted of the following three steps: 1)- modifying the base energy model (and bulk airflow model, in some cases) or creating a new base model reflecting the team's design concept; 2)- running a series of "what ifs'" on one parameter of the design --such as shading configuration, wall assembly composition, or size and orientation of inlet and outlets in natural ventilation-based schemes; 3)- reporting back results to studio team, discussing design options and iterating steps 1 through 3 to refine and debug the model(s). At the request of the instructors, simulation results produced by the students were to be less about monthly energy consumption totals and more about hour per hour diagnosis of critical periods of the year from a comfort standpoint.

To investigate one relevant issue in their team's design proposal, the DA member in each team first devised a DA setup on paper and then built a scale mock-up that was installed onto an existing test cell instrumented with three thermocouples (Figure 3). Data collected from the test cell and from the weather station was used to compare the DA measurements with the results of a TRNSYS (figure 4). DA team members also reported to the rest of the team.

Figure 3: A simple mock up of a shading device installed onto an existing test-cell equipped with three thermocouples (low, mid, high).

The teams met regularly during the development of the design by the studio students. The BPS modeling

results and the DA investigation results were to be part of the studio final presentation. Both BPS+DA course students and studio students participated in the joint final review that was also attended by two guest reviewers: a practicing mechanical engineer and an architect with an advanced degree in building simulation.

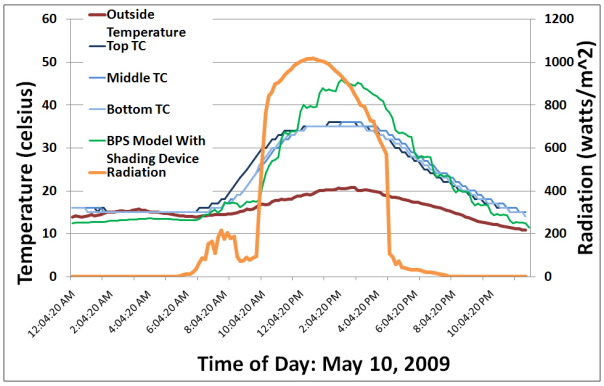

Figure 4: 24-hour plot showing global solar radiation and comparing temperature measured in the test-cell equipped with the shading device shown in figure 3 and predicted in TRNSYS model.

ANALYSIS OF OUTCOMES

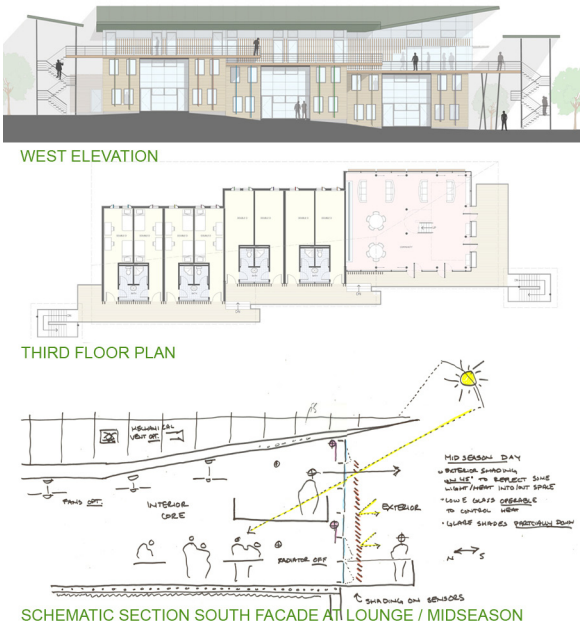

Figure 5: Project by Lauren Bergeron (Studio), Matt Dean (BPS), and Felipe DaSilva (DA) a proposal to add a third floor with a communal lounge to the south end of the building. The BPS model and DA mock up concentrated on studying the impact of shading the lounge space at the third floor. To account for air stratification in the lounge, this space was modelled as three superimposed zones in TRNSYS and CONTAM.

Collaborative studio work

The guest reviewers' opinions were generally positive and encouraging both in terms of the students' work, the underlying collaborative process, and the teaching setup. The view of the reviewers was that the joint teaching setup had helped produce interesting and satisfactory results in the studio and overall. The studio work succeeded in demonstrating a concern for energy, environmental factors and building envelope performance.

Figure 5 and 6 illustrate two of the design proposals. The project shown in figure 5 approaches the upgrade of the existing building envelope by proposing to remove the existing roof and to build a third floor with independent access. Here, the DA and the "what if" BPS investigations primarily concentrated on studying the proposed extensively glazed third floor lounge. The project shown in figure 6 proposed retrofitting the building envelope and replacing the existing unlit interior staircases with exterior ones. The team proposed to join two units horizontally by means of a communal space.

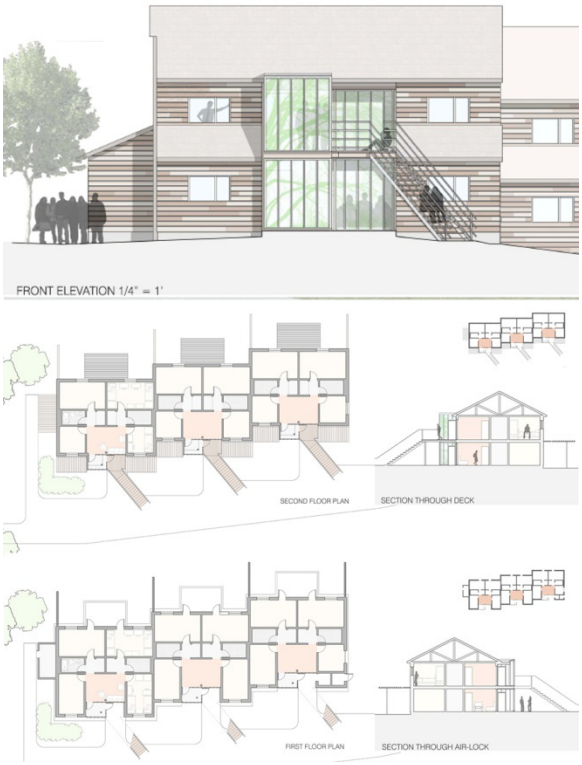

Figure 6: Project by Dan Cross (studio), Jessica Johnson (studio), Taylor McNally-Anderson (BPS), and Brittney Sullivan (DA), a proposal to link units at the same level to create a greater sense of community. The exterior stairs acts as communal seating areas.

This team's BPS investigation (see figure 2) consisted of creating new energy and bulk air flow models

reflecting the design in order to compare several natural ventilation options as well as window shading options. Figure 3 and 4 show this team's DA mock-up shading and measurement results.

Surveys

Five out of 11 studio students filled a generic online evaluation for the studio that did not discriminate specifically the opinions regarding the consultancy-based portion of the semester. Overall, the studio students rated the studio as educationally valuable (3.8 over 5). In informal verbal exchanges, the students expressed their interest in the consultancy-based teaching format. Students responded positively to the idea of upgrading the student housing building to make it more attractive and energy efficient. The textual analysis of the open-ended questions in the studio online evaluation shows that a few students found the instructor-driven arbitrage between different design options somewhat intrusive and the consultancy-based portion of the studio to be too directed. A few studio students questioned the reliability of the building modelling results prepared by their BPS team member.

Out of 14 in the BPS +DA course, 11 students (five architects and six engineers) completed a two-part survey. Part one included open-ended questions. The textual analysis of a few open-ended questions indicates that both architecture and engineering students: a) bought in the collaborative intent and overall approach of the course; b) found the course very intensive and sometimes overloaded; c) felt sometime thrown off balance by the unusual format of the course, the collaboration with the studio and its associated workload and uncertainties; d) found that the communication between BPS and DA subgroups was insufficient. Several students wished they had more time to learn the software tools.

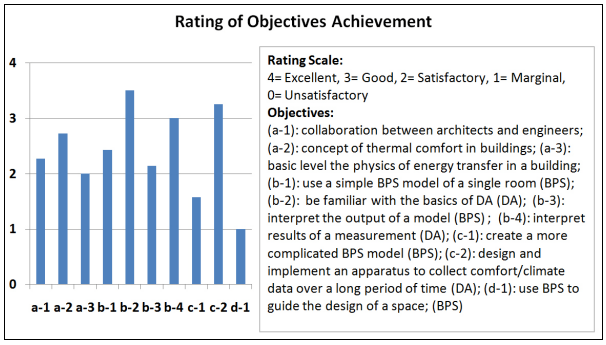

Figure 7: Graph showing the average scores of objective achievement calculated from the course students' responses to a survey.

Part two asked the students to rate the degree to which they felt the courses objectives had been achieved. Figure 7 shows the average rating on a zero to four scale, taking into account the BPS or DA specificity of each objectives.

Predictably, the data shows that students felt the objectives a-1-3 ("collaboration", "thermal comfort" and "basic physics") had been achieved better than the more advanced BPS objectives. On average, confidence in having achieved the specific objectives was greater in the DA students than in the BPS students.

With an average score of 2.4 and 2.1 BPS students expressed some intermediate confidence at the level of using a simple BPS model (b-1) and interpreting results of model (b-3) respectively. The architecture students in the BPS group felt more confident at modelling (score=3.0) while the engineering students felt more confident at interpreting results (score= 2.25). With an average score of 1.6, the BPS group expressed a lack of confidence with the extent to which the "create a more complicated BPS model" objective (c-1) was achieved. Here too, the architecture students were more positive than their engineering counterparts on this point with 2.3 and 1.0 scores respectively. Finally, the capstone objective, "use BPS to guide the design of a space" (d-1) is seen as slightly above and below "marginal" by architecture students on average (score= 1.33) and by engineering students (score= 0.75) respectively.

Instructors' view

The teaching setup gives interesting results and seems to work in terms of exposing students to a BPS- (and DA-) informed design process. It is challenging to all participants, students and faculty. The required coordination between the studio and the course was greatly simplified with the same instructor teaching both the studio and the BPS portion of the BPS+DA course. The timeframe in this model of concurrent studio and course in which student learn some BPS (or DA) over the first ten weeks of the semester and then apply this knowledge in the context of a collaborative design effort at the end of the semester is, as expected, too short to provide the student with any real expertise at building modelling. Like Derome et al. (2004), we find the collaboration between the architect and the engineers as well as between the BPS "specialists" and the DA specialists to be a challenge to all involved. Predictably, students experience some difficulty orienting themselves within this unfamiliar collaborative multi-disciplinary framework/ integrated design process.

Arguably, the voluntarily limited size and scope of the thermal and airflow models might have had both a positive and a negative effect. On the positive side, students did not feel that the software tools were too difficult and impinged their collaborative effort. On the negative side, because during the design collaboration

phase the scope of the simulation effort was narrowed down to studying primarily one issue through iterative "what ifs", students possibly neither did get a sense of a whole design investigation, nor did they get a sense of grasping the full potential of the software. This might perhaps explain the relatively low scores obtained on average by the advanced BPS course objectives as shown in the previous section. In addition, we see there a potential risk that a student might "oversimplify" and reduce the inherent complexity of the design process to an exercise in optimization on one unique parameter. Finally, although one might regret the lack of confidence by the student in creating more complex models, the other side of the coin is that student might better appreciate the modelling work done by a specialist and feel compelled to employ one when necessary.

The lessons learned from delivering the BPS portion of this joint teaching setup include to: a) avoid content overload; b) communicate effectively to students short and medium term goals; c) emphasize that the setup is as much about experiencing a collaborative workflow than just about learning pieces of software; d) find less intrusive ways to help student that are stuck or debugging model; e) beware of the danger of wanting to be too precise and too "real" in the design options and modelling efforts as to avoid having students feel "nudged" into particular design options or modelling approaches; f) keep insisting that students keep the size of their building models to a minimum –i.e. resist the architecture students natural tendency to create large models; g) reinforce tirelessly the notion in the student that the work does not stop with the creation of the model and that the interpretation of results is essential to the process; h) recognize that the students at this stage of their learning have a limited ability to critique their own BPS models; i) reinforce the exchange between BPS and DA specialists to help ground BPS modeling in physical reality.

Future Roles: BPS Consumers and Triage-ists

Despite the somewhat sobering survey results above, we think this teaching setup not only begin to prepare the students to operate in a BPS-rich design environment in the future but also showcases the benefits of the early collaboration between the designer and the BPS consultant. We believe that the students in both the course and the studio are on a path to becoming at least better-educated consumers of simulation prepared by specialists.

For those students who exhibited a promising attitude and a genuine interest in the BPS tools they were introduced to, we believe they are on a path to possibly become what we propose calling triage-ists. In our view the triage-ist uses simple BPS models to explore potentials design options before the certified BPS simulation specialist begins to intervene. Assuming these students keep developing their nascent building modelling skills independently or through graduate studies, we envision how these graduates could be engaging in a proactive investigation of the field of design possibilities even before the first line of the design is drawn. Alongside with other initial analyses such as site, climate and feasibility analyses, the BPS-triage-ist's role could help focus the design team on the integration of environmental factors in the design. Ideally, a few intriguing ones among the options the triage-ist would have uncovered through his/her early scouting of the design space would be brought to the attention of the BPS-specialist for further investigation.

CHOICE AND USAGE OF BPS TOOLS

We have had several prior experiences teaching with TRNSYS, CONTAM, and CpGen. In contrast, it was the first time we introduced THERM 5.2 in the studio. We find that these tools complement each other well and are adapted to our particular teaching setup. Specifically, we value the capability of integrating in a TRNSYS' thermal model a bulk air flow component obtained through CONTAM with wind pressures computed using CpGen. For the novice modeller, the workflow of obtaining wind pressure profile data with CpGen and then reformatting it for CONTAM becomes the support to learning about one factor influencing a building's physical response. This is just one of many examples of how we use the software tools as learning tools. Along the same lines, the relative inconvenience of having to create two models –one in TRNSYS and one in CONTAM—of the same spatial arrangement help illustrate the specific concerns associated with modelling different physical phenomena. Similarly, TRNSYS's well-mixed zone air assumption provides an opportunity to touch upon modelling assumptions, limitations, and workarounds such as modelling several zones stacked on top of each other to better account for air stratification in a tall room. Software tools equipped with substantial online help menus such as CONTAM's provide valuable opportunities for the student to independently learn more about the physics underlying the tool.

Our teaching model emphasizes the early inclusion of BPS investigations in the design process and promotes the use of simple models. Simple one-zone models representative of a typical condition/configuration in a building can teach us a lot about what is happening from an energy flow standpoint in a space.

TRNSYS' and CONTAM's transient simulation capability is essential in helping the student develop a thermal intuition (Strand and Fisher, 2000). For

example, the on-screen plot in TRNSYS of the operative temperature in a room enables the student to visualize and possibly "internalize" the changing comfort conditions in the zone. Similarly, the visualization capability in THERM 5.2 and CONTAM greatly help the student's learning when it is accompanied by the accurate interpretation.

Besides it collaborative dimension, our teaching setup emphasizes the iterative dimension of the design process. To help with this, improved post-processing functionalities that enable the student to easily compare different options or iterations and that help communicate the results in a compelling way to the design team are desirable. The scenario-comparison based online tool "Design Advisor" (Glicksman, 2006), points in the direction of one possible answer to this concern.

Ultimately, we would argue that the suite of tools we have selected is adequate to educate students toward becoming BPS consumer or triage-ist. Unlike their younger counterparts, advanced architecture students who are projecting themselves in their future professional career, perceive positively being introduced to professional-grade software. Through its user-friendly new building creation wizard, TRNSYS is such a professional-grade software that is nonetheless accessible to the novice.

FUTURE WORK

How to improve the level of achievement of the course objectives listed above? Because of the lack of space, we will outline here only four potential directions for improving the teaching setup presented in this paper. The first two are practical in nature. The other two are more conceptual evolutions to the consultancy-based teaching model.

a) Running more "what ifs" seems beneficial to both broaden a team's design space search and to begin to investigate interdependencies between different parameters. Engaging more multi-criteria building modelling would avoid the danger of the flawed view of modelling as a narrow, single-criteria optimization exercise. To achieve this, the BPS+DA course and the studio might begin collaborating earlier in the semester.

b) Delivering the BPS+DA as a four credit-hour course would better acknowledge the multi-disciplinary and lab-based nature of the course, as well as would also help us leave more space to the students for individual explorations. More time might allow students to grasp more of both the BPS and the DA content of the course.

c) Enforcing a more proactive use of BPS might benefit this consultancy-based framework. As we envision it, a proactive integration of BPS in the design process would imply that the BPS-teammate/consultant generate a number of simple one-zone simulations prior to the finalization a building concept, possibly even prior to any line drawn on paper. Unlike the collaboration timeline described in this paper in which teams first outlined a building concept and only later began to model targeted "what if" scenario(s), in the proactive model, ideas would be tested to a certain extend prior to making design decision and help guide the team's design decisions. In our view, the proactive use of BPS would reinforce in the student the point on the benefits of using BPS early in the design process.

d) Introducing a greater knowledge asymmetry between participants might help this setup better achieve its objectives. For examples, the students in a graduate architecture and engineering BPS course could consult with an undergraduate architecture studio. Arguably, introducing such a knowledge-level asymmetry better replicates the interaction between a junior designer and an expert consultant in practice. The lower level studio student might be better prepared as a BPS consumer, while the graduate BPS consultant might become better prepared as a triage-ist.

CONCLUDING REMARKS

This paper has examined how to prepare architecture students to working in a BPS-rich environment when all they learn about BPS is contained within one semester. The analysis of the outcome of a multidisciplinary consultancy-based, and design-based teaching setup with a five-week design collaboration between a course with BPS and DA content and an architecture studio shows encouraging results.

In the particular case of the unique exposure to BPS– be it in an isolated course or through a complex joint teaching setup— our view was that the exposure should primarily: a) explicitly reinforce in the student the notions of iterative design methodology, and collaborative approach, b) promote the early insertion of BPS in the design process by means of simplified models and "what ifs" investigations, and interpretation of BPS results (in particular, learning to interpret time-dependent plot of transient simulation), and c) help the student develop a thermal intuition and understanding of buildings physical behaviour grounded in (DA) measurements and observations.

Should architects stay away from BPS tools and leave the simulation to the BPS specialist? Based on this and other past teaching experiences, our answer to this question is 'no' in the context of architecture education and 'yes, perhaps' in the context of architecture practice. As our teaching setup illustrates, there are simply too many learning opportunities afforded by

BPS' presence in the school. However, unless architecture education massively integrates BPS throughout its curriculum, the graduating students will continue lacking the building simulation experience that could enable them to model complex buildings accurately. Nonetheless, we argue that the limited exposure to BPS the graduate of our teaching setup have received can contribute to a more seamless integration of BPS in design practice.

We have speculated on the emergence of two figures: the consumer and the triage-ist. The consumer understands a BPS-inclusive design workflow and is aware of the benefit that early input from BPS can have on design decisions. The BPS consumer also has a grasp of the potentials and limitations of BPS and displays some ability to interpret and form an opinion on BPS results presented to her/him. The triage-ist possesses similar ability and is also capable to accurately model typical conditions and draw adequate conclusion from the model. The triage-ist proactively explores the space of potential designs for a particular project in parallel or prior to the arrival of a BPS consultant on the design team. The triage-ist prospers in a forward-looking firm that recognizes the value of early input from BPS simulation on making good early decisions. Ultimately, our speculating on the emergence of the consumers and triage-ists as actors in architecture practices requires further investigation. Survey data is needed on both the kind and extent of BPS instruction in architecture schools and BPS use by graduates in architecture offices across North America.

Finally, we would argue in favour of the professional building modelling community overcoming its suspicion of the non-specialists described in this paper and engaging these individuals for who they are: potential allies in need of advice and mentoring. BPS specialists should realize that they have an educational role to play when interacting with these graduates within architecture offices.

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