BUILDING PERFORMANCE SIMULATION IN UNDERGRADUATE MULTIDISCIPLINARY EDUCATION: LEARNING FROM AN ARCHITECTURE AND ENGINEERING COLLABORATION

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ABSTRACT

The paper is concerned with the integration of building performance simulation within a collaborative/ multidisciplinary higher-education environment. The paper presents a semester-long setup in which a course attended by both architecture and engineering students and jointly taught by an architect and an engineer ultimately collaborate with an undergraduate architecture design studio on proposing upgrades to an existing building.

As an introductory-level course with building performance simulation (BPS) content, it strives to incorporate other components in addition to the collaborative design one. These other components aimed at grounding the BPS into physical reality are: back-of-the-envelope hand calculations, physical modelling, and data acquisition measurements.

The authors find that leaving aside the goal of achieving refined analytical methods of BPS to instead endeavour to establish a proper collaborative framework between BPS consultant and designer (here represented by the course attendee and the studio attendee, respectively) early in the design process delivers interesting results in terms of student understanding of how buildings work.

INTRODUCTION

As do many other authors (Clarke & Maver, 1991, Degelman & Soebarto, 1996), we believe building performance simulation (BPS) can help students gain valuable insights into complex building physics phenomena. This paper is a contribution to the question of how and when to implement the integration of BPS in undergraduate architecture and (general) engineering design education. This line of inquiry occurs at a time when US universities reflect on means of integrating the concepts of sustainability into their curriculum and when society increasingly requires from building design and construction professionals the ability to deliver both more comfortable and more environmentally sound buildings.

In this paper, we strive to address the following question: what are appropriate methods to integrate a design component within a one-semester long introductory undergraduate course on BPS? Our method of approaching this question combines a literature review and the design, implementation, and prediction a few of the outcomes of a new two-component teaching setup offered at our university during the spring of 2009. The intent of this teaching setup is to contribute to the preparation of future professionals that are able to operate in collaborative and BPS-rich environments. The teaching setup is composed of a course and an architecture studio running concurrently that initially work independently from each other and later collaborate over the final five weeks of the semester. There is a unity of command and continuity of purpose between the course that is co-taught by the authors --an architect and an engineer-- and the studio that is taught by the architect co-author of this paper. The course is entitled Arch-Engr (and is referred to as such in this paper) because of its dual population of both undergraduate architecture and engineering students, both of whom are introduced to BPS and data acquisition (DA). During the collaboration phase, teams of Arch-Engr students act as consultants to teams of studio students.

The proposed teaching setup reflects and draws from both instructors' backgrounds: practice (the architect) and test and measurement methods (the engineer). The instructors have eight and five years of teaching experience respectively.

The paper should be of interest to faculty in higher-education teaching architecture and/or engineering students who are interested in integrating BPS in their coursework. Developers of BPS tools should also find in this paper some insight on how such an introductory teaching setup uses certain BPS tools.

Part I of this paper includes a breif literature review on the subject of BPS teaching formats in higher education. Drawing on lessons from past teaching experiences integrating BPS by the authors, the first section of Part II lists the underlying principles, goals and constraints that have guided the authors when conceiving of the new course. The second section of Part II contains an examination of a few aspects of the collaborative setup between the course and the studio. The third section of part II outlines the architecture studio and the integration of BPS prior to and during the design collaboration with the BPS "specialists" from the Arch-Engr course. The fourth and final section of Part II describes the Arch-Engr course design and implementation; in particular, it outlines the sequence of learning activities aimed at preparing Arch-Engr students to play the role of BPS-capable consultants to their architecture studio counterparts.

Part III explains the palette of BPS and DA tools being used in Arch-Engr and the studio. Part IV examines the outcomes of this teaching set-up/experience and its implementation and Part V lists some questions related to potential ways of developing such a teaching setup in the future.

LITERATURE REVIEW

This literature review does not claim to be comprehensive but begins to illustrate the wide variety of ways in which BPS is approached in higher education. For our purpose, we distinguish between the courses that train BPS modellers from those that merely use BPS within the teaching.

The methods employed to train to BPS tend to have in common their rigorous attempt to not let the specifics of the particular software have precedence over the general principles of how building simulation works and its underlying equations (Hand, 1993, Hand and Crawley 1997, Strand et al., 2004).
In contrast, the methods to teach with BPS tend to be quite diverse. Variation is observable at the level of BPS tools involved, extent of the training in the tool(s), mix of associated activities, course formats, etc.

Our review finds a greater number of courses with BPS content at the graduate and post-graduate level than at the undergraduate level (Batty and Swann 1997). Undergraduate or graduate/postgraduate status does seem to make a difference in terms of the depth of study of the inner workings of BPS. However, the rigor applied at the graduate level to understanding how BPS works (Augenbroe, G. et al, 2008) seems often echoed at the undergraduate level in the emphasis of underlying fundamental mass and energy balance equations (Norford, 2006).

Among the many course types and formats, we find the stand-alone courses within which BPS are used to help understand HVAC concepts (Strand, 2001), and courses with BPS content that are integrated with other CAD modelling courses (Hamza and Horne 2007). There are course formats that link energy simulation modelling to post-occupancy measurements of an existing building (Degelman & Soebarto, 1996). BPS can be mixed with scale-model measurements and energy balance calculations to analyze a building design (Norford, 2006). While the above courses models all strive to have the student adequately understand what he/she does when using a particular simulation tool, their primary objective is to bring an insight into how building works to the student.
For us, a significant distinguishing factor is whether a design component is part of the setup involving BPS. A related issue is whether or not the designer is the one that prepares he BPS model(s) (Charles & Thomas, 2009).

When it comes to integrating BPS and design in architecture schools, we find widely varying teaching formats and course duration. BPS efforts in the undergraduate studio might be linked to a building technology course (Roberts & Marsh, 2001). Dedicated BPS stand-alone courses can address both software training and its use within a design endeavour (Soebarto, 2005). Undergraduate and graduate architecture design studios can introduce BPS to all or a subset of the studio attendees or tap into exterior talents to deliver BPS modelling results (Daubmann, 2001, Charles & Thomas, 2009). Finally, a number of BPS-oriented graduate programs first train students in BPS in order to enable them to prepare their own simulations when designing in the design studio.

METHODOLOGY: ELEMENTS OF THE DESIGN OF THE ARCH-ENGR COURSE

The design of the Arch-Engr course has evolved from various course formats with which the authors have "experimented" with over the years (Charles & Thomas, 2009). Learning from these prior teaching experiences, we concluded that the new Arch-Engr course ought to:

- achieve a balance between three types of insights on how buildings work: an insight gained through BPS, an insight gained through basic physics calculations, and an insight gained from sensing/measuring physical phenomena;
- introduce every student in Arch-Engr to the basics of both DA and BPS;
- provide the students with the choice to "specialize" in DA or in BPS;
- continue to explore the potential of a dual student population and of co-teaching;
- allocate enough time to analyzing data/results by limiting the size and scope of BPS models;
- emphasize more quick "back-of-the-envelope" calculations in order to check simulation results plausibility and order of magnitude;
- increase the weight of the design component in the course by engaging into a real building design problem concerned with environmental sustainability;
- accelerate the bonding between architecture and engineering team members in the hope that it will facilitate the subsequent collaboration;

- maintain the "fun elective" character of the course [i.e., leaving the responsibility of in-depth teaching BPS to graduate programs].

While most of the points above are self-evident, some might raise questions in the reader. Why, for examples are there architecture students in the Arch-Engr course? Is BPS not the turf of mechanical engineers and physics degree-holders? Our answer is two-fold. First, we can acknowledge that simulation has become fairly common in architecture practice. More and more architects are generating their own simulations –albeit primarily in the form of visualization and realistic renderings. Second, with our ultimate goal of preparing architecture and engineering students for future professional collaborations in BPS-rich environments, we see numerous advantages to have a class composed of both architecture and engineering students working side by side and learning to bridge the gap between their cultures and educational backgrounds.

What about this "specialization" option (i.e. picking either the BPS *or* DA option)? We are comfortable with the fact that different students in Arch-Engr have slightly different experiences and learning outcomes from the course. We actually think that the fact that half of the class knows more on one subject -DA or BPS- than the other half makes the need for collaboration between the two groups more evident.

Why is the design component of the course so necessary? Why are we not content with simply analyzing an existing building with BPS? Our answer is that because such an analysis exercise would be done "after the fact," on a completed design, it would place BPS at the end of the process and therefore would send the wrong message on when BPS should be used. In contrast, we see design as a synthesis, a moment of application of prior knowledge and articulation of it in the form of a building "concept" that encompasses multiple dimensions. We also believe that the students can learn important lessons about the nature of the design process from it. In addition, while the analysis exercise might reinforce the notion that one needs a lot of detailed inputs to produce a model, conversely, a design problem will introduce the student to working within uncertainty and limited inputs. With the design problem, the student will have to adjust her/his model's precision and comprehensiveness to match the progress of the design as well as test various "what if" options.

Our desire to accommodate a full-blown design component to the Arch-Engr course, along with the constraint of operating within the confine of one semester, brought us to the decision of linking Arch-Engr to an architecture studio.

THE COLLABORATIVE SETUP: ARCH-ENGR. AND STUDIO

As previously discussed, to ensure compatibility and continuity of purpose between the two courses, one of the two authors who co-teaches the Arch-Engr course is also instructing the architecture studio.
Thematically, the idea emerged that the collaborative design effort between Arch-Engr and the studio should be concerned with the upgrade/modification of an existing dormitory building on our campus. We saw five advantages to this choice: 1) it appropriately places performance issues and understanding of physical, climatic and human comfort factors to the foreground of the design thinking; 2) it suitably limits the number of design issues the students have to deal with within the short timeframe of the design; 3) it showcases retrofits as one significant means of achieving greenhouse gas emission reduction; 4) the students can directly experience the building; 5) the cellular and repetitive organization of the building lends itself well to discussing modelling strategy and extend (one room vs. whole building model).

In such a dual -Arch-Engr course and studio- setup, the weight of the design is carried by the studio. The Arch-Engr students are able to take part into the design effort as a consultant in charge of helping articulate a "building concept" and preparing various BPS models iteratively. The architecture studio designers are therefore not distracted by having to learn a software suite and can concentrate on developing the design and learning to hold their own role within the consultant-designer interaction.

AN OUTLINE OF THE ARCHITECTURE STUDIO

The studio is an advanced elective undergraduate studio that meets three times a week for three hours each over the 14-week long semester. The studio has 11 enrolees, none of whom are also enrolled in Arch-Engr. The studio examines three problems successively over the length of the semester. The central common theme across the three studio problems is the building envelope considered at a detailed construction level as well as in relationship with a building concept encompassing aesthetic, energy, environmental, and cultural dimensions. The goal of the studio is that students approach design as an integrated exercise that considers construction issues along with other issues such as systems, energy, ventilation, at a whole building conceptual level.

The thematic continuity across the three studio design problems is aimed at facilitating the studio student's foray in the collaborative effort with the Arch-Engr course students. As mentioned earlier, studio students are exposed to BPS modelling primarily as consumers, although all are introduced to climate analysis tools and to Design Advisor (Glicksman et al., 2006). Prior to the third, collaborative, studio design assignment, studio students prepare physical models and receive energy and acoustic simulation results prepared by the instructor and two BPS-capable student tutors on an ad-hoc basis. A few exterior architecture and engineering consultants also intervene on studio review days. Consistent with the detailed study of building envelopes, three volunteer studio students with appropriate design credentials are introduced to a 2-D thermal bridge modelling tool and a 2-D heat and moisture transport tool.

The third problem is five-weeks long and focuses on an existing dormitory building on our campus. Students, working in teams of two, generate design proposals on how to improve the building envelope as well as how to add program and to modify internal spatial arrangement to foster play, work, and a healthy community life. Each studio team works with a BPS+DA Arch-Engr team toward formulating various design alternatives and then developing one of them further.

A DESCRIPTION OF "ARCH-ENGR"

The elective undergraduate course runs concurrently with the studio over the 14-week length of the semester. Arch-Engr meets twice a week for 80 minutes each time. In a spirit of collaboration across disciplines, Arch-Engr's enrolment is nine architecture students, nine engineering students and one environmental science undergraduate student. All are third and fourth year students except for two engineering sophomores. In terms of coursework background, architecture students have had a mechanical and electrical equipment course and most of the engineering students have had one semester of thermodynamics.

In terms of BPS use, the semester is broadly organized in three successive parts: introduction, analysis and design. The first part of the course lasts three weeks. It introduces and/or reviews background material on environmental sustainability, the collaborative non-linear design process, building physics, and comfort, as well as BPS and DA. Students visit the dorm room to be studied and work in groups to document both the room and the building (plans drawings, wall material catalogue and U-values, details of construction, measurement of mechanical ventilation air supply, infiltration rates estimate, occupants' survey, etc). After two introductory sessions on DA and BPS, Arch-Engr students are asked to volunteer to join one of two sections specializing in one of these two fields.

The second part of the semester lasts five weeks. For the first five class sessions, students are taught in the two separate, identically sized, sections (DA or BPS). Students receive further instruction in either the principles of DA by the engineer co-author of this paper, or in the basics of BPS modeling by the architect co-author. Students are also introduced to various lecture material and simplified calculation methods. Students complete in-class and at home labs. The DA section proceeds to develop the data acquisition system for use in the dormitory room while the BPS section learns how to model the room using energy simulation software TRNsys, then using bulk air flow Contam (Dols and Walton 2002), using also pressure coefficient input obtained from CpGen (Knoll 1997). All students practice how to interpret data and/or results that they and other students have generated. Students work in groups to prepare an intermediate report on how the dorm room works from an energy flow and comfort standpoint in light of the BPS results and DA measurements. After learning climate analysis tools using typical meteorological year data, all students make use of the simulation models prepared by the BPS teams to perform a series of "what if" tests aimed at evaluating the impact of various parameters changes -orientation, building envelope composition, amount of glazing, position of shading devices inside vs. outside, etc- on the space under study. This phase culminates with the presentation of the report by the Arch-Engr students to the studio students during a joint session. Together with the Studio students, Arch-Engr students begin to brainstorm and discuss improvement ideas.

During the five-week long third and final part of the semester, DA+ BPS teams of Arch-Engr students act as consultants to a studio team with whom they meet on a regular basis as part of their homework. They first collaborate with their studio team-mates in framing a design strategy for the upgrade/modification of the dormitory building. They then analyze ways of modelling the design at hand. With some support, they prepare the model(s), analyze, share and discuss the results with their studio team-mates who continuously develop the design including its construction detail aspects. They iteratively improve upon the model(s) reflecting the evolving design concept. They also document their effort. Data acquisition "specialists" analyze the design proposals and devise on paper a data acquisition system that would adequately capture a key aspect of the design. Time and resource allowing, one of the studio upgrade proposals for the building envelope is built by studio members as a mock up approximation and is instrumented by the DA specialists in Arch-Engr. The acquired data is then compared with the results obtained from the BPS modelling.

Each Arch-Engr team writes a final report that retraces the collaborative design investigation. The intent of this final assignment is to have the students reflect on the process of collaboration as well as the quality of DA and BPS results they have generated.

CHOICE OF BPS TOOLS

Both the Arch-Engr course and the studio provide an exposure to how and when some BPS tools are used. The proposed dual teaching setup is fundamentally about using BPS as a means to gain an understanding of how a building works and acquiring a thermal intuition (Strand, 2004) more than teaching BPS proper. Consequently, we have chosen tools that have transient capabilities such as those offered by TRNsys (Klein, 2000) and Contam (Dols and Walton, 2002) because they convey the dynamic behaviour of buildings better than tools that only provide a monthly or annual energy use. The online plotter capability in TRNsys virtually places the student in the room. Interpreting a temperature plot certainly lacks a strong immersive quality and pales in comparison with the CFD and augmented reality environments developed by Malkawi and Srinivasan (2005) for example. Nonetheless, a student equipped with a sense of how to relate her/his own sensations with primary indicators of thermal comfort (air temperature, mean radiant temperature, relative humidity) can "get a feel" of the conditions in the room. When paired with teaching about comfort, transient temperature plots are serving the purpose of helping the student understand change occurring in the room/building. The choice of software is not disconnected from the need for students to learn to relate their personal sensory experience with actual measurements (of temperature, relative humidity, etc).

On one hand, the lack of visual interface of the model itself in TRNsys 16 is a drawback; the visual inspection of a model's geometry is not possible. On the other hand, the abstraction of the model to a series of text entries requires discipline, planning, and reflection prior to acting on the part of the modeller. There seems to be here quite a valuable lesson to be learned by the non-expert designer who might otherwise have a tendency to "draw before thinking".

Another element in our choice of software such as TRNsys 16 is that we try to provide students in Arch-Engr with a glimpse into professional grade software used in practice. The existence of a wizard to generate building models in TRNsys 16 is helpful not only to generate a model base very rapidly, but also because it enables the student to investigate /reverse engineer how the model is put together. For the student, this represents a first step on a path to understanding how the model/software works.

With our emphasis clearly placed on achieving an insight on how a "building works," we find it important to allow ample time for the interpretation of simulation results. In Arch-Engr, learning to model the room in TRNsys-Contam-CpGen (Klein, 2000, McDowell T. et al. 2003) (Dols and Walton, 2002) (Knoll, 1997), starts with very simple models of the room using Type56 (with adiabatic walls to adjacent rooms. The first modeling effort is analysis-based, striving to reflect the building as it is and to calibrate the model to reflect the on-site DA measurements.

The BPS tools used by the studio students are Design Advisor (Glicksman, 2006) for general introduction, the Weather Tool (Marsh, 1996) and Climate Consultant 3.0 (Li and Milne, 2004) for climate analysis. A subset of qualified volunteers also are introduced to Therm 5.2 a 2-D conduction and radiation heat-transfer analysis tool (Mitchell et al., 2006) and WUFI-ORNL, a 2-D heat and moisture transport tool (Karagiozis et al., 2001). The tutors use CATT acoustics (Dalenbäck, 2006) and TRNsys to provide acoustic and energy modelling.

The following principles guided the selection:

- Tools that help introduce general concepts and present a general picture of the room's behaviour that includes energy, light, acoustics, materials;
- Ease of use and minimal disruption of the design process (because the designers are still novices);
- Capability of generating imagery that can be integrated in the presentation of the design;
- Thematic adequacy: the thermal bridge and moisture transport tools concentrate on detail study of building envelopes. Limiting factors are the extent of the material libraries.

CHOICE OF DA METHODS AND TOOLS

As in the choice of BPS, the desire to expose students to software used in typical real-world applications guided the choice of DA software. As such, the students were introduced to National Instrument's LabVIEW. Another guiding principle was the desire to have a package that was flexible enough to accommodate many different sensors (i.e. instead of using the software that is typically included with some sensors). With LabVIEW, students are exposed to the workings of instrument communication (USB and SERIAL) as well as acquiring voltage signals using an analog/digital (A/D) converter. The A/D converter is used so that students can build their own simple "state-type" sensors, for example, if a window is open or closed or if a door is open or closed. Building the hardware and associated signal conditioning for a sensor of this type is an eye-opener to students who are used to "plug-and-play" equipment.

Again, as with the BPS, we do not expect the students will become experts in programming in LabVIEW. The intent is to introduce the subject to them and inspire them to learn more. Perhaps most importantly, however, is for the students to be able to understand and appreciate the intricacies of data acquisition systems.

OUTCOMES

Because the Arch-Engr course and studio have barely begun as of this writing, the remarks in this section are mainly predictive in nature. From among many possible outcomes, this section outlines the following three notable ones: 1) knowing how buildings work; 2) collaboration between Architecture and Engineering students; 3) using BPS and DA tools.

1) Knowing how buildings work

Arch-Engr students can gradually understand how the building works during the analysis phase and benefit from having access to both physical DA measurements and BPS results. Studio students, who receive the analysis from the Arch-Engr students and who only visit the dorm room once or twice, do not have the benefit of the multi-weeks investigation. How far and when do these students understand how the building works? It will probably take some testing of a couple of design ideas and receiving feedback from their consultant counterpart. At the very least, we take comfort in knowing that the mere notion that there is something to be understood of how a building works from both thermal and comfort standpoints is in the student's mind when designing. This is already a significant improvement over the unfortunate situation in which designers seem exclusively preoccupied with form to the detriment of environmental connectedness.

2) Collaboration between Architecture and Engineering students

What kind of collaboration is happening? Is it successful? The collaboration takes place at multiple levels in our dual setup: between students with different background within Arch-Engr, between Arch-Engr students and studio students, and between instructors. We predict that enforcing the requirement that students within a group of four in Arch-Engr meet outside of class time to teach each other what they are learning in their respective DA and BPS sections will require a lot of nudging on the instructors' part. We predict a partial success to the collaboration between Arch-Engr teams and Studio teams on the third design assignment. We foresee that it will be difficult for the novice designers and BPS consultants to see design synergies and opportunities that capitalize on the building behaviour over the whole year.

When the collaboration phase between Arch-Engr and studio occurs, we see the studio teams still having to learn how to set a direction for the design, and how to clearly outline and communicate a "shared concept" that encompasses not only spatial, functional, constructive and aesthetic dimensions but also energy, climate and performance aspects as brought by the BPS consultant. We believe that the setup will ultimately help studio students begin to learn to listen to the BPS+DA consultants and to know what questions to ask of them. It will also help them become more enlightened consumers of BPS, who understand how BPS help them and their design,

3) Using BPS and DA tool.

We predict that it will be difficult to adjust the BPS models to the in-situ DA measurements. The primary reason is the complexity of the space/room –quite packed with three occupants- will test the assumption of a one-zone model. We anticipate the need for input from the instructor and outside consultants in helping framing potential simulation models consistent with particular studio team designs, in helping making sense of the results, as well as in providing quality control of the BPS models.

Making sense of BPS results and communicating effectively what they mean to the studio designer teams will be a main challenge to the Arch-Engr teams. Because of this, we expect that the implementation of BPS within the design context will raise interesting questions on how best to approach the modeling effort –the extent and precision of the model, and its selectivity toward certain aspects on the design. A very basic issue will be how to manage the delivery of BPS results to the studio teams in a timely fashion to influence positively the design.

Because of the short timeframe, we expect that individual teams will not really have the time to compare between several different design options with the BPS. It seems more likely that BPS "specialists" will investigate several variations of a base case by means of the "what if" method to which they were exposed to earlier on. However, the different designs developed by the collaborative teams will provide some material for comparison between design options.

In studio, we predict that the select students who will conclusively engage in WUFI-ORNL and Therm 5.2 will use of their output visualizations in their final presentation but might have difficulties to explain them.

FUTURE WORK

This section begins by briefly listing some questions to be examined in relation with expending from the teaching setup presented here. It continues with a succinct outline of software features that we feel would accommodate the particular needs of such introductory course using BPS.

Among the questions to be examined are:

-How to extend the ramifications of this teaching setup at the undergraduate level within our school of architecture? Can we help Arch-Engr students practice their skills by providing BPS in other studios in the future?
-How is this teaching setup scalable? How can we reach more students?
-What would a graduate version of this course setup entail?
-Should Arch-Engr's student population include construction management students? Would this adequately provide them with the necessary experience of the value of early BPS-powered collaboration, as well as educate them on the value of prototypes/mock-ups in the design process?
-What would a consultancy-based model of design education entail? How much better would a sequence of studios with BPS-capable consultants position students to address environmental issues in design?
-With the previous two bullets touching upon the notion that an evolution toward a shared authorship of a design is occurring, how does BIM (Building Information Modeling) fits in this picture?
-What kind of rigorous assessment tools can we develop to help us control progress and evaluate student learning?

A short wish list to developers. We identified the following features we think could be integrated in the kind of simulation tools we use to better serve such an introductory course and facilitate the access of users with an introductory knowledge of BPS (i.e. encourage self-training)
-Help with the setting up the input and checking whether an input is too low or too high in order to prevent/limit garbage-in garbage-out situations.
-With our intent to have students gain an insight into how a building works, wizards that do the hard work are good. Eliminating all ambiguous terms, acronyms or jargon that do not make sense to a novice would be a step in the right direction.
-Integrate more analysis of weather data and microclimate analysis. Can tools prevent us from perfecting a bad solution such as using air conditioning where natural ventilation is appropriate?
-In TRNsys, having the capability of keeping track of successive options and comparing their performance (similar to that found in Design Advisor or eQuest). Such a capability can also be improved if it includes the comfort-related aspects: how many hours are uncomfortable and for what reason? Is their distribution in time a problem?
-In Design Advisor, when a new scenario is evaluated, it seems that it would make the software more transparent and educational if it showed what calculations are being executed.

RECAPITULATION AND CONCLUSION

This paper has presented an introductory one-semester long undergraduate-level teaching setup that involves an elective course and an elective advanced architectural design studio running concurrently and that collaborate over a period of five weeks. The collaboration between the student teams in the course and student teams in the studio involves an actual architectural design work centered on designing upgrade measures for an existing dormitory building on our university campus. The course is attended by both architecture and engineering students who work together in mixed groups. A consistency of intend across the course and the studio is ensured by the same instructor intervening in both of them.
While Arch-Engr is an introductory, course not burdened with the responsibility of delivering full-blown BPS-capable graduates, the course does attempt to set a proper framework promoting the early collaboration between architect and engineer on a design problem. Furthermore, the portion of the semester that is allocated to teaching how to proceed with BPS modeling is counterbalanced by other activities such as DA and quick calculation in order to place BPS in a broader context. The teaching setup tries to prepare future professionals to integrate BPS results into the design process. It also tries to inculcate or reinforce general lessons on the nature of the design process such as its iterative nature, the ill-defined nature of its problems, and the benefits to approach it non-linearly and collaboratively.

We find that it is beneficial to have both the architecture and the engineering students first working together within Arch-Engr to begin to bridge differences of culture, learning style, etc. Both groups begin to develop a clearer view of how the other group thinks and of the advantages of an earlier collaboration. We see it a necessary step toward the preparation toward the design collaboration with the studio. While this teaching setup only achieves these outcomes to a limited extent, we see the side-by-side initiation of architects performing BPS themselves and the education of the simulation specialists in closer contact with designer as part of the remedy against the often-noted fact that in real life architectural design processes, building performance simulation efforts are too often engaged after their results can be put to effective use.

Beyond the teaching setup described here, one can begin to imagine a consultancy-based model of teaching design that would draw heavily from BPS as well as from physical modeling. We can see how such a consultancy-based teaching model could serve to focus the attention of the collaborating architecture and engineering students on environmental issues of growing importance at this time.

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