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THREE APPROACHES TO INTEGRATING BUILDING PERFORMANCE SIMULATIONS TOOLS IN ARCHITECTURE AND ENGINEERING UNDERGRADUATE EDUCATION

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ABSTRACT

The paper reflects on a series of past and on-going teaching experiences by the authors involving building simulation tools in undergraduate architecture and engineering education. All of the teaching experiences attempt to replicate the powerful consultant-architect interaction as found in high-quality architecture practices. After an overview briefly retracing the evolution from teaching formats in which the instructor is a provider of simulations, to various formats in which the students produce simulations as part of the design process, a newly created interdisciplinary course is presented. The course is jointly-taught by the authors (an architect and an engineer) and its audience comprises undergraduate architecture and engineering students. The course emphasizes early collaboration within an iterative and non-linear design process. Simulation tools are used to help bridge the gap of culture among participants and bring a better understanding of physical phenomena at play in the building. The course's Design-Simulate-Instrument framework attempts to balance the analytical and the synthetic/design through a sequence of precedents analysis, design problem, computational and physical modeling, followed by measurements, data acquisition, collection and analysis.

INTRODUCTION

The topic of this paper is building simulation in undergraduate education in the AEC (Architecture, Engineering & Construction) sector. Through a little over a dozen courses and studios across the last eight years, the authors have been experimenting, first independently and now jointly, with different modes of teaching/learning with simulation tools to undergraduate architecture students. The driving force behind these experiments stems from lessons learned from practice that magnified the importance of collaboration between architects and engineers at the early stages of design, and particularly so, when designing sustainable buildings/architecture. Working collaboratively with talented engineers equipped with building performance simulation capabilities was a powerful experience. Throughout the years, the motivation for developing these various courses and studios has fundamentally been to replicate this kind of powerful, revelatory moment in the studio environment. Making the studio or a course a simulation-rich environment has provided invaluable opportunities to render more understandable, otherwise hard-to-grasp, physical phenomena at play in a building. With most students, simulation software has the capability to unveil, even if only partially sometimes, new understanding of complex interrelated phenomena.

In our view, and in light of the lessons learned reflecting on the our teaching experiences with them, building performance simulation tools are nothing less than a new kind of powerful lens that augments one's ability to better comprehend the physical world of buildings.

The work we have done can be placed in contexts that are external and internal to architectural practice and education. As viewed externally, a significant motivation for introducing building simulation tools in the classroom is the growing need for (future) practitioners to be prepared for the challenges of addressing complex problems in a sustainable way. In this context defined by a sense of urgency to find remedies to a number of preoccupying global environmental problems, building simulation tools are potent allies to the teacher and the learner. As viewed internally, our teaching initiatives should be compared to established models of including simulation software in students training (Hand, 1993; Batty and Swann, 1997; Norford, 2006) . There are design studios within which students prepare their own simulation(s) (Soebarto, 2005), for example lighting and shading studies, and classes with instruction in simulation, which are becoming fairly common occurrences in architecture curricula, particularly at the graduate level. Similarly, the "design studio with outside consultant" model is frequently found at schools of architecture. It seems that it is one of the prevalent models when a consultation framework is sought[1]. In this model, the

[1] Typically the outside consultant, an architect or an engineers, often comes more or less regularly to provide critique (at the desk with the student or more likely in a pin-up review to the students in a studio

outside consultant is the provider of an expert opinion but simulation tools are most of the time not part of the conversation/critique environment. This latter point will help the reader identify what is original about our approach.

We note that while the courses presented in this paper do not claim to achieve the high level of student proficiency demonstrated by qualified practitioners, we believe they come as original contributions to design education.

The paper is organized in three parts. The first part of the paper briefly outlines several new architecture courses developed by one of the authors between 2001 and 2007 in which building simulation tools have played a role. Two models of ways how building simulation is integrated in the course are outlined. The second part of the paper presents a new course jointly taught by the authors to a group comprised of both undergraduate architecture and engineering students. This course was designed to have them collaborate by means of employing simulation tools to learn elements of a design methodology particularly adapted to sustainable building design. The course is an attempt to go one step toward 'bridging the gap' of culture between architects and engineers. Finally, the last part of the paper begins to examine some of the pros and cons of these teaching experiences and offers some perspectives to future improvement of some of the pedagogical models involved.

PART I: PAST EXPERIENCES

REPLICATE: FROM INSTRUCTOR AS SIMULATION PROVIDER…

The prior teaching experiences were fundamentally attempts to find ways to replicate the kind of enlightening interaction that takes place between the architect and the building-simulation capable engineer or consultant at the early stages of a design.

We[2] feel that it is important to replicate that kind of consultation in a school of architecture. The reasons are that it emphasizes the power of collaborative practices and it establishes the principle of a distributed/shared authorship of an architectural design. Furthermore, it powerfully highlights the importance of understanding the physical phenomena at work in and around a building

In our past efforts to replicate this architect-consultant interaction in the undergraduate architecture studio or in other formats, we have primarily used two models.
The first model of making buildings simulation tools part of the 'conversation' has consisted of having the studio instructor (the author) be the one who prepares all simulations for all students or groups of students in the studio. We find this model to be consistent with an undergraduate design education in which only so many issues can be engaged and controlled by the non-expert designer. We tend to prefer, for that reason, to provide the "service" ourselves and let the student concentrate on her/his design (vs. spending time being distracted by having to learn the software). We see this model as one that achieves the goal of approximating the architect-consultant framework. Because the topic of the studios in questions lead to exploration of wind driven natural ventilation options, mostly computational fluid dynamics were provided to the students under this model.

While this model gives very good results and has shown a lot of potential in terms of positively influencing the student designs and in terms of anchoring the notion of the iterative nature of the design process, its major drawback is that it is very time consuming for the instructor.

SHIFT: …TO VOLUNTEER STUDENTS PREPARING SIMULATIONS

Besides continuing to operate under the 'instructor as simulation-provider', in the last few years, the author has experimented also with models in which the responsibility of producing simulations was shifted onto volunteering students. In one particular instance, a studio with two joint sections and two instructors[3], involved both instructor-provided simulations and student-generated ones. The volunteering members of the studio were informed of the expectation that they would be performing their own simulations (with some support) and that they possibly would prepare some simulations for their classmates as well. The students' participation was presented as a "bonus". It was highlighted to the students that no negative consequences were to be feared if they failed or

section). Sometimes schools of architecture offer a well known consultant a visiting professorship. She/he gives a series of lectures, most likely open to the whole school/department, and critique in one or more studio. She/he might also teach a seminar course.

[2] The courses described in this part were conceived and conducted by one of the authors, P. Charles only, but for stylistic reasons and because both authors agree on the analysis of these experiences, we have elected to use "we" throughout Part I.

[3] With one of the instructors not versed into any kind of building simulation, P. Charles & E. Pavlides, "Wind" Macro Studio, RWU, with Eleftherios Pavlides, Spring2007.

abandoned the modeling work. Only positive, bonus points in recognition of their effort at using the simulation tool for themselves and possibly for some of their studiomates, were to be expected. Students received support in their modeling efforts in the form of crash courses offered to groups limited to three students, which were held outside of class time in two to three sessions for a total of no more than six hours each in Contam, TRNsys and Flovent. Armed with their minimal knowledge of the software and with some on-the-fly support, students undertook to model very coarse and simplified versions of the design they were developing.

On average, out of three students who received a crash-course in one of the software packages, one student really 'got it' and was quasi-autonomous with regard to performing simulations, one required a lot of step by step guidance, and one abandoned the effort almost immediately and as a result did not prepare and run any simulations. Based on our experience, only the most secure and mature designers are able to integrate the simulation tool(s) in their design process.

Although modest, the shift of responsibility induced here, along with the release from some simulation preparation time, was very appropriate for this particular double-section (two instructors, 21 students working as 12 groups on various projects) studio.

Along the same lines, in another instance, we recently[4] tested a model of a fast-paced three credit-hour workshop with a strong intertwining of analysis phases and design/synthesis phases. All students initially received an instruction in CpGen, Contam and TRNsys. Furthermore, they were acquainted with reading from or projecting obstructions on a sun path diagrams among other skills. Midway through the mini-semester the design problem was undertaken: what to do with an existing, slightly neglected art building on campus. The class which was composed of ten junior and senior architecture and three engineering students was divided into three balanced groups with an engineer in each group and with at least one person per group having volunteered to work on the simulations. The rest of the group members worked on other analysis and design issues. To support the student in their modeling effort, several outside-of-class sessions were organized to model the building "as is". The greater analytical content of both the course and the design problem made it an obvious choice to have each of the three groups explore its own solution (what if the building if full HVAC, what if the building is fully naturally ventilated, what if the building has mechanical ventilation) and explore variations concerning upgrades in the building envelope. Air precooling and preheating was also modeled, along with some radiant cooling option for some select spaces within the building.

In both examples, volunteering plays an important role: the instructor looked for motivated students, and students receive introductory instruction in professional-grade building simulation tools at just the "cost" of some outside of class/studio time.

In these two examples students actually modeled and ran the simulation themselves with some support. In terms of learning, the underlying philosophy at play here is one that prefers big leaps over incremental steps. Certainly, the "big leap" approach requires absolutely that one (in an act of ownership of one's learning process) regularly steps back and analyzes what, to use a architectural construction analogy, foundational knowledge needs to be acquired to reinforce the learning edifice.

In both models some important lessons can be learned about the power of collaboration and responsibility.

We see Schön's (Schön, 1983) reflective practitioners at work in these two models.

OUTCOMES

Both models outlined above open a window for the student revealing what simulation tools can do for them. Furthermore one can hope that the experience of working with the simulation tools might trigger a curiosity and an interest into learning more about them, possibly through a graduate program. Closer to us, we witness how some of the undergraduate architecture students who had shown the most interest took advantage of the opportunity to develop their burgeoning skills by taking the class that we present in part two of this paper. It is our hope that we can nurture the development of a small group of committed and knowledgeable undergraduate students that can becomes building performance simulation-capable internal consultants for the rest of the school.

SIMULATION TOOLS SELECTION CRITERIA

The building performance simulation tools selection criteria have been influenced by the fact that the effort described above started as under the 'instructor as simulation-provider' model, and by the fact that the instructor has an interest in comfort-achieving solutions that are not exclusively air-based. In other words, a light bias against indiscriminate use of HAVC has favored tools with explicit radiative phenomena and natural-ventilation modeling-capability. Lighting simulation tools have not been part of the 'blend' of

[4] Winter Intersession 2008, Special topics: Sustainable Systems, P. Charles, Instructor.

software recently[5]. The reason behind this is not to minimize their importance. The reason is that, because energy and airflow (bulk or CFD) simulations are more disconnected from the visual realm – the overwhelmingly prevailing realm in architectural design - we find them a better entry point for a re-thinking how we design with the whole environment.

When it is the instructor that provides the simulation to the students, the issue of the difficulty to learn the tools looses (most) of its relevancy. Otherwise "learnability" plays a role. In our opinion, the difficulty of learning the software can be offset by an added effort on the part of the learner. This has been dealt with by asking for motivated, design-secure volunteers and by highlighting that an introduction to professional grade simulation software is a plus on one's résumé[6].

Finally, our preference goes to two kinds of tools. First, those tools that can do the most but also let us do simple, coarse simulations to be later refined incrementally. Second those tools with good enough results visualization (CFD, Contam) and good ability at conveying the dynamic nature of the environment (the transient capability of TRNsys as seen on the screen).

PART II: NEW COURSE AT RWU

In the most recent teaching experiment taking place at RWU this spring semester of 2008, the authors, an architect and an engineer, will be co-teaching a group composed of both advanced architecture and engineering undergraduate students. As the course has yet to be taught (as of this writing), clearly what is included here are predictions of what will occur. This course is a new elective offering in both programs. In addition to teaching building modeling techniques to the students, it is being offered in an attempt to promote collaboration between the architects and engineering students and, after they graduate, professionals.

Besides being collaborative both at the instruction level and at the student population level, the course also attempts to integrate building simulation tools within an iterative design process articulated around a 'triangular' structure considering successively: design-model-instrument. In this model, the value of feedback among these components toward achieving sustainable building will be stressed. In order for the students to operate around the entire triangle, we also plan to teach them how to test those predictions via measurements (i.e. the "instrument" portion of the triangle). It is hoped that this will stress the importance of modeling building performance in physical form when appropriate.

The concept of having architecture students and engineering students in the same class is not new. In fact there are currently seventeen ABET-accredited (Accreditation Board for Engineering and Technology) Architectural Engineering programs in the US[7]. On the spectrum of complete isolation of the two programs to complete integration, Architectural Engineering is arguably an example of the latter end of the scale. There are also non-accredited programs like the one at Princeton University (Mark and Billington, 1995) .Other examples of in-common course work include having the students take business courses together (Wilkinson and Scofield, 2002) and working with students on a remote basis (Martin, et al. 2007; Fruchter and Lewis 2003; Karakaya and Senyapili 2008; Dong and Leslie, 2006). The difference in the present case is having the two populations learn simulation tools and to test them by making measurements. An established and successful program similar to this exists at the University of Virginia, called the ecoMOD project (Quale, 2005).

COURSE WORK: DESIGN AND SIMULATION

The first task in the design phase of the course will be to look at what has been done in the past by preparing a thorough analysis of a built precedent. This is a very common type of exercise/assignment in a school of architecture used most often as a preparation for design. We anticipate that the precedent analysis could potentially be the first instance of culture shock for the engineering students, who, for the most part will be completely new to this activity.

Too often in a studio course, the precedent study is fairly short, and certain aspects which are essential to understanding the climatic context of the precedent in sufficient depth are not achieved. When dealing with precedents whose designers claim to achieve energy efficiency or environmental sustainability, the students "analyses" tend to be mere repetition of these claims made by the architect or the architecture magazine writer.

Precedents analyses are typically presented to the whole class/studio which ensures that all of the class members know about these particular examples. We try to improve the quality of the analyses in two ways: (1) with a careful selection of precedents from which the students can choose, students will have access to not just the claims of the architect but also, in some cases, post-occupancy data. This enables the student to

[5] Although it has been the case in a summer studio using Lightscape, IIT, 2001, P.Charles, Instructor.
[6] As long as one does not, as we advise it strongly, claim full proficiency in the said software.

[7] www.abet.org

take a more critical look at the claims, and (2) beyond the usual redrawing and diagramming we will ask the students to model the whole or parts of the building with energy modeling software. The modeling will be performed in teams composed of architecture and engineering students who will put together a reasoned synthesis of the project.

Although they are not the designers of the precedent, the students should gain a clear understanding of the design thinking at play in the original design. In our view, it is an important, analytical component of the design process that is activated here through the act of "re-constructing" the design. It is true that the object under scrutiny in the precedent analysis is the only option/design left to analyze, the one that becomes "evident" because it was the one chosen and ultimately built. This comes in contrast with the multitude of alternate answers/design the design team must have considered (typically this is lost, although sometimes it is partially documented).

After preparing and presenting the precedent analyses, the students will work in teams to design a small office building which will conform to established performance guidelines. The students will use simulation software to guide their designs. We expect that the teams at this point will evolve in such a way that the work is compartmentalized: one member might do the drawing while other members might perform various simulations, for example. After the design and simulation stages have progressed to a certain level, we plan to have the students take some aspect of that design (most likely a small portion of the building envelope), install it in a test cell (Manz et al., 2006), (Leal and Maldonado, 2008) and make measurements to see how it changes the energy requirements of the proposed building and of the modeled test cell plus tested piece configuration.

SIMULATION TOOLS SELECTION CRITERIA

In addition to a regular spreadsheet, it is our plan to use numerous other pieces of software in this course. The software are listed in what follows along with a brief explanation of why there were selected. Two climate analysis software tools (The Weather Tool[8], and Climate Consultant[9]) were selected for their ease of use, their graphic interface and ability to represent data visually. One comfort analysis tool (Comfort Tool by ASHRAE) is used in conjunction with plotting comfort zones under different conditions onto a psychrometric chart. A window performance calculation tool (WIS, Window information System)[10]is used to introduce in a graphical manner such concepts as transmission. The ability of WIS to consider window systems with ventilated cavities as well as adjustments of shading devices geometrical properties – i.e. orienting the slats of a venetian blind at different angles- were a determinant in its selection.

The multizone bulk air flow modeling tool Contam[11] was selected for its ease of use, graphic interface, transient capabilities, and ability to link with TRNsys to account for airflow coupling between zones and with the outside. A wind pressure profile generator web-based software (CpGen[12]) was chosen for its ability to predict dimensionless static wind pressure coefficients at the facade and roof of buildings, taking into account the influence of nearby obstructions. The data obtained through CpGen is used in Contam. The pressure profiles produced this way will be used instead of or in comparison with tabular data from the literature.

A transient energy analysis software (TRNsys 16[13]) in conjunction with other libraries[14] was selected for its transient capability, professional grade, ability to account for radiant-based climate modification solutions, and its integration of bulk airflow by means of reading a Contam output file.

Finally, a computational fluid dynamics (CFD) package (Flovent[15]) was also selected because of its relatively flat learning curve, and because CFD's visualization capabilities captivates students' imaginations. It will be used in conjunction with some fairly crude wind tunnel modeling.

It is not intended to have every student learn every piece of software described above. In line with the teaching experiences presented in part I, we prefer to have the students work in groups within which knowledge of the software is represented. As in previous courses we nonetheless see the need for the whole class to have a basic knowledge of or minimal exposure to all software -. With the quantity of software to be introduced, we will rely again significantly on time segments outside of the scheduled class time.

COURSE WORK: INSTRUMENT

The goal of presenting to the students the techniques of data acquisition and analysis is so that they will be at

[8] http://www.squ1.com
[9] http://www2.aud.ucla.edu:16080/energy-design-tools/

[10] http://www.windat.org/wis/html/index.html
[11] http://www.bfrl.nist.gov/IAQanalysis/
[12] http://cpgen.bouw.tno.nl/cp/
[13] http://sel.me.wisc.edu/trnsys/features/
[14] www.tess-inc.com and www.transsolar.com
[15] http://www.flomerics.com/flovent/

least able to critique a particular physical model of a design from the standpoint of its actual performance.

Additionally we hope that it will give the students a basic understanding of the operation of systems that monitor the performance of a building. In our new course, this subject will be presented in several ways, spanning from students building a simple current meter, or performing an energy audit on a common appliance (a refrigerator) up to, as mentioned previously, testing the performance of some aspect of the office building they designed in a "test cell." In the process of learning to measure these quantities, we hope that the students will gain also a qualitative knowledge of what different magnitudes of environmental quantities feel like – for example, what does a 0.5 m/s air current feel like compared to a 1 m/s air current.

Arguably, the best way to monitor the performance of a building is to set up computerized-data acquisition systems to record the data automatically. To make the computerized measurements, the students will use the student edition of LabVIEW, from National Instruments. This package was selected because National Instruments offers a wide variety of hardware for performing measurements which are easily interfaced using LabVIEW. Its graphical programming language allows a relatively easy learning process so that the students will be able to make quick progress with this portion of the course. This software is commonly used in industry and in higher education so it is probable that the students will encounter it again.

PART III: CONCLUSION AND DISCUSSION

In the first part of this paper, we presented the past experiences of one of the authors with regards to integrating simulation software into undergraduate architecture studies. Some of the courses –design studios- followed the general model of the instructor serving as both a consultant and simulation provider to the students. Such a setup emulates the architect-consultant arrangement that is commonly found in professional practice. Other courses were more directly an attempt to teach the students how to use a suite of software in both analytical and design contexts. In the second part of this paper, we presented what we propose to teach in a collaborative way to architecture and engineering students in the upcoming spring semester of 2008. This new course is a step in the direction of understanding the role of building performance simulation tools can play in collaborative education.

In what follows, we first discuss the lessons learned (both positive and negative) as a result of the past teaching experiences presented in this paper and how these inform the upcoming class. We then proceed in briefly discussing why the particular software packages were chosen.

LESSONS LEARNED: PROS

In general, integrating building simulation tools in the architectures studios and courses has shown to provide the students with valuable insight into physical phenomena at play in the building, particularly when the software have transient simulation capabilities. They offer great lessons to students on the dynamic nature of the environment and about comfort.[16] They expand the realm of the design beyond the mere visual, opening new avenues toward an 'architecture of the seven senses'. [17]

Furthermore, after several design options have been explored and one particular scheme has been selected, the ensuing multiple simulation runs help reinforce in the student the fundamental notion of the iterative nature of the design process, from idea, to drawing, to model (physical and computational), to evaluation of the design, to better ideas, to drawing, etc.

The "instructor as simulation-provider" as its own advantages:

It illustrates how simulation can and should be part of the design process (including early on in the process). Students receive feedback without being 'distracted' by learning the intricacies of one or multiple software packages. This framework requires the designer/student to understand her/his role relative to the role of the consultant more accurately: this of proposing and understanding thoroughly her/his proposal and of communicating it effectively –by establishing clearly during the designer/consultant conversation what is essential to the scheme-. -

The faculty is seen as really helping the student – putting in a lot of extra effort. A favorable environment is thus created within which the Faculty is afforded greater than usual as well as better legitimized opportunities to influence the designs. This can be used in the service of reinforcing the idea of the collaborative nature of the architectural design.

The model provides motivation for the faculty member to learn the software extensively

The model in which some volunteer students only learn a limited set of software has shown to work and to benefit from the flexibility afforded by the fact that

[16] Mahadev Raman, ARUP, New York City, Lecture at Illinois Institute of Technology, 2001.

[17] A case made by author Juhani Pallasmaa (1994).

different people in the class and/or the groups learn different software and contribute different elements to the ensemble. This model teaches students about responsibility and collaborative skills.

LESSONS LEARNED: CONS

The "instructor as simulation-provider" model has drawbacks.

The model is very time consuming for the faculty member, thus making it sometimes difficult for her/him to provide timely feedback to students, particularly so if the studio size is above 8 students. For large studios, this issue can be addressed by reducing the number of designs to be modeled –i.e. if students work in small groups instead of individually-. This might not always be desirable, in particular in the case of students experiencing difficulties to 'achieve' on their own.

In the "instructor as simulation-provider" model, none of the students learn how to use any software. Arguably, this might reinforce the culture gap mentioned earlier if the students is not placed in a situation in which she/he can adequately conceptualize her/his role relative to this of the consultant.

In the model in which some volunteer students learn some software, only a fraction of the students learn the software. Students will lack autonomy if they only learn one software in isolation from other interrelated software.[18]

FUTURE IMPROVEMENTS:

Arguably, a point of general concern could be that by acting toward bridging the gap with our fellow engineers we might be widening the one already present within many architecture departments between technical and non-technical courses as regretted by Allen (2005) and Oakley &Tripeny (2007).

As we design our jointly-taught upcoming Spring 2008 class, we plan to implement improvements bearing on:

-Finding ways of reaching out to/touching more students at other levels of undergraduate studies.

-Nurturing interested junior students –architects or engineers- to have them become simulation-providing assistants/consultants themselves with other studio students during their senior year.

-Trying to introduce prototypes/ large scale mock ups used for visual feedback, for studying issues of construction, and for measurement of building performance.

-Associating "real" consultants to the effort.

-Maintaining and developing the pragmatic and responsive structure present in the past teaching experiences presented earlier and exploring further the potential of collaborations.

Beyond next spring's horizon, we see areas of developments in the broadening of the simulation tools palette to include daylighting and moisture transport. We also see a value to collaborating with structural engineering and façade engineering as an attempt to touch upon true comprehensive design.

Admittedly some of the software packages used in the past and in the upcoming course can be considered advanced and professional grade, and as such one might question their usefulness at each stage of the design process. Why then, did we choose of advanced, and at times, hard-to-learn software? Why not also integrate tools deemed more appropriate to early investigation. First, with Allard (2003), we regret the lack of powerful early conceptual design stage tools. There are tools that are particularly appropriate for introductory course where the goal is clearly that every student acquires the same knowledge on a same set of issues. With limited class time, we have made the choice to concentrate on a smaller pool of software, some of which are indeed harder to learn and use, but for which we can tailor very simplified simulation exercises that capture most of what early-stage software does. With the exception of the CFD package, we can work around the complexity, we can simplify the model, make it more coarse, "bend it a little" to get a first feedback of the design. By doing so we learn important lessons on the nature of modeling, on what result to trust, we learn healthy circumspection. Because in our pragmatic approach, we do not insist on having every student take the course and complete it with the exact same skill set than her/his classmates, we feel we are able to some extent to free ourselves from the issue of the adaptation of the complexity of the tool to the level of studies. In any case, we frontload the class with a lot of software early, so that there is time later on to use the software in an analysis and design context.

We are clearly aware that under the second and third models of teaching described in this paper students, based on their talent and their motivation, will complete the class having somewhat different experiences. Hopefully, most will grasp what building performance simulation can "do for you". We imagine that these students could remember that there are consultants out there they should talk to at the earliest stages of a design, or even, could convince a client that such a framework is paramount to achieving sustainable (or simply 'good') architecture projects. At

[18] The case in point was the students who had learned Contam but not TRNsys were at a disadvantage compared with students who had learned TRNsys and later could rapidly learn Contam on-the-fly or independently.

the other end of the spectrum, are we “creating” “hybrid creatures” “architect and engineers?” Probably not quite. We would nonetheless hope that we’ll have contributed to motivate future professional to explore both the potential of collaboration and the potential of building simulation tools.

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