# Mind the Gap: Building Simulation in the Architectural Design Studio

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## 1. ABSTRACT

**Building modelling and simulation approaches are increasingly being utilized in architectural design studios to guide and inform the design process and offer evidence-based feedback on proposed building performance. The development of intuitive and simplified simulation interfaces has greatly contributed to achieving this integration. One aspect that is often overlooked is the workflow that governs and regulates integrated design, which can have significant impacts on final design outcomes. Currently there are numerous software packages available for building performance simulations. This makes it challenging to select an appropriate tool that provides accurate results yet allows a designer to make informed architectural decisions with a designer-friendly interface. Furthermore, workflows to incorporate simulations into the design process proved to highly impact student's project design integration. Yet, it is not clear what type of workflows are successful to achieve this goal, under what conditions, and/or for which building and site typologies.**

**This paper addresses these issues by first reviewing three different workflows for integrating building performance simulation processes and highlighting their strengths and weaknesses. Second, a comparative case study approach was employed to test three of the most common workflows in three different integrated design architectural studios at the senior and vertical studio levels as well as in two courses that run parallel and complementary to the design studios. The workflows, processes, and the resultant student projects were further analyzed based on criteria for better integrated design and architectural excellence as outlined in the American Institute of Architects Committee on the Environment (AIA COTE) Top 10 Student's Competition.**

**Third, to situate the pedagogical case studies' results within a larger context, a survey of the AIA COTE Top 10 student competition award recipients over the last five years was conducted. The results are summarized in a pedagogical framework that outlines best strategies of the type of workflows, software, design process used, methods to achieve desired interaction between design process and analytical feedback, and metrics for educators to evaluate the success of this integration and their learning outcomes in the design studio. The goal is to help bridge the gap between the building design and simulation within the design studio's creative process for more integrated design outcomes.**

## 2. INTRODUCTION: INTEGRATING SUSTAINABLE DESIGN IN THE ARCHITECTURAL STUDIO

How does an integrated design studio in architecture programs perform within the context of sustainability? This is, of course, an obtuse question that relies heavily on the multitude of definitions of terms such as sustainability, integrated design, and studio performance. While there are multiple definitions and perspectives that guide the use of these terms and their pedagogical applications in architectural education, this paper views architecture technology knowledge and studio design process as an integrated whole. In this perspective, the design studio —a term used to describe a physical environment, a teaching event, and a pedagogy— is conceived as the vehicle where knowledge is gained and applied at the same time in a hands-on teaching approach (McClean, 2009). For the context of this paper, sustainability and sustainable design are viewed as pluralistic concepts that do not solely rely on the ecological technical domain of knowledge but rather on a framework of 'logics' with different interpretations of sustainable hierarchies and importance (Guy and Farmer, 2001). This pluralistic view of sustainability guides the integration of knowledge in the design studio related to the attributes of space, building image, source of knowledge, technology, and ontology.

2.1 Integrated Design Taxonomy:

The term 'integrated design' is often used to represent the consideration of environmental systems, structure, building envelope, materials, assemblies, etc. in the design process. Even when we specifically look at sustainable design, there are many topics that can be included such as designing for wellness, community, social equity, and economy (AIA 2019a). The complexity of addressing integrated design is often overlooked, due to the lack of guidance on how various aspects can be incorporated in a typical design studio. A report by NCARB (2012) showed that only 25% of educators and licensed architects believed that integrated design should be acquired at the application level. The same report showed that only 14%

of interns and architects licensed in the past 10 years acquired knowledge of integrated project design by completion of an accredited architecture degree program. These results suggest the need for further emphasis on integrated design in architectural design studios and for developing methods that facilitate design integration at various levels, types, and scales.

2.2 Integrating Technical Aspects of Design for Sustainability

This paper focuses on the integration of building performance simulation in the design studio. There are several pathways and tools that can be utilized to address environmental design concepts and assess their effectiveness. These tools include rules of thumb based on climate analysis such as guidelines generated by Climate Consultant, calculators such as PV Watts, simplified simulation tools like COMFEN, and detailed full-building simulations that can inform main design decisions using software suites such as IES-VE and Lady Bug Tools. In this paper we define building performance simulation (BPS) as the practice of utilizing a simulation software to assess building energy, daylight, solar radiation, air flow, heat transfer, or sound performance. Hence, the mere use of rules of thumb or simple calculations is not included in this discussion.

2.3 Problems with Technical Integration in the Design Studio

The integration of BPS in design studios has gained increasing attention in efforts to improve the quality of architectural design. This goal influenced methods used for teaching environmental systems as well as curricular structure (Azari and Caine 2017). Allen (1997) proposed a second studio – a design studio with a simplified space program, in addition to the conventional design studio—to introduce technical topics to architecture and engineering students. However, this model is likely to distance technical knowledge from conventional design studios that often include more complex programs and conceptual strategies. Other methods for integrating environmental principles into design studios include a series of projects using rules of thumb (Demirbilek et al. 2010), and the use of BPS tools through an architecture-engineering course collaboration (Charles and Thomas 2009).

In order to integrate BPS in design studio pedagogy, it is important to consider the workflows, time, and effort needed to generate useful results. A general challenge for integrating BPS is the time required to master technical knowledge at the fluency level of applications in design decisions while resolving other design decisions related to site, form, spatial configuration, and program (Grover, Emmitt and Copping, 2019). This challenge is amplified by a common misunderstanding that architectural technology is second to design rather than an integral part of the process (Allen, 1997; Demirbilek, et al., 2010). A parallel challenge is related to student's ability to model a valid building geometry and thermal zones that can be used for building simulations (Göçer and Dervishi 2015; Dogan and Reinhart 2013). Another challenge is maintaining a seamless workflow between different simulations and design decisions, especially when conducting detailed simulations. Lastly, different building types, contexts, and student technical knowledge levels can benefit from a slightly different approach for integrating BPS. For example, it might be appropriate to conduct preliminary energy simulations on simplified geometry (shoebox), compared to detailed simulations as the design progresses. This paper aims to shed light on these workflows and their use in architectural design studio.

2.4 Managing Expectation with Integration: Simulations in the Design Studio

The research aims to provide an overview of a sample of workflows for integrating simulation in the design studio and test them using a participatory action research (PAR) framework. In this qualitative framework, the researcher is embedded in the study and report on its findings from an active participant position (Grover, Emmitt and Copping, 2019). The PAR paradigm is highly applicable to an educational context such as the design studio. The inclusion of multiple cases of PAR from two different schools as well as the content analysis of cases from the AIA COTE Top 10 Competition for Students winning entries provided a triangulation of the data sources to enhance the conclusions. It should be noted that this study is not attempting to generalize the topic of integrating simulations in the design studio nor it is attempting to provide an "optimized" solution or approach to achieve this pedagogical goal. The objective of this paper is to report on this study in a way to open-up the dialogue and share knowledge from a number of cases for simulation workflows integration so as to set a framework for discussing and sharing knowledge among architects and architectural educators in the design studio.

## 3. MODELS OF SIMULATION WORKFLOWS IN THE ARCHITECTURAL DESIGN STUDIO

A 2012 study by the National Council of Architectural Registration Boards (NCARB 2012), showed that most architects don't understand the implications of their building design on energy use and the environment, even though they acknowledge its importance. A follow-up report by the AIA (2019) on building performance integration shows that this knowledge gap can impact the profession's resolution on climate change, collaboration with other building design professionals, and application of evidence-based design in practice. One of the problems with achieving this proper integration is related to the design process workflow in architectural studios and the perception that including this technical knowledge will result in more constraints and time commitment that takes away time from the spatial design of the building (Demirbilek et al., 2010). By clarifying some common misunderstandings and describing a framework for integrating energy and environmental simulation within the design studio, this paper aims to reduce this knowledge gap in the design workflow of architectural studios.

High-performance design, including energy efficiency, is becoming as fundamental of a design service as meeting basic programmatic, budgetary, and life-safety needs. A deliberately multidisciplinary approach to building performance—including energy and environmental impacts performance—coordinated and managed by the architect, should be embedded into every architectural studio workflow. There are currently three workflow models to achieve this integration: (1) Early stage "Shoebox" model, (2) Design development "70/30 DD" model, and (3) Parallel/Cyclical integrated model (Figure 1). The following is a description of each workflow model. It should be noted that these models are not mutually exclusive and they may occur embedded and integrated in one another during the different phases of a project's design process.

3.1 Shoebox Model Approach

In this approach, the design studio starts with the development of a conceptual "Shoebox" digital model and run it in a BPS package. The shoebox model explores some sensitivity studies related to the impact of the site, climate, insulation, glazing percentages, and schedules on energy and environmental performance of the building type and context of the studio project. This stage typically precedes the formative design stages and massing in the studio and provides early decisions support guidelines to help students make informed design decisions to meet the energy and performance metrics they set-up as goals for their project.

This approach is similar to the one recommended in the Leadership in Energy and Environmental Design (LEED) where the project team conducts simple box energy modeling before the completion of schematic design to identify energy and load reduction strategies (LEED v4). Due to the simplified geometry, number of inputs, and reduced thermal zones and areas, this approach is widely used in design firms because it reduces the amount of time and effort needed for modelling and simulation in early design phases. In design studios, the shoebox model approach is particularly useful when simulations are done by a group of students. It eliminates the need to develop massing details or aesthetics. Once this phase is completed, each student can draw conclusions and apply them to their own design.

3.2 Design Development 70/30 Approach

This approach typically integrates simulation and modelling later on in the design process. It starts after the designer concludes the schematic design stage. Simple rules of thumbs, sustainability design charrettes, and bioclimatic design principles are usually employed to guide the early design stages of the studio project. At the conclusion of the schematic design phase, modelling and simulation activities are employed at 70% design completion and before starting on the design development

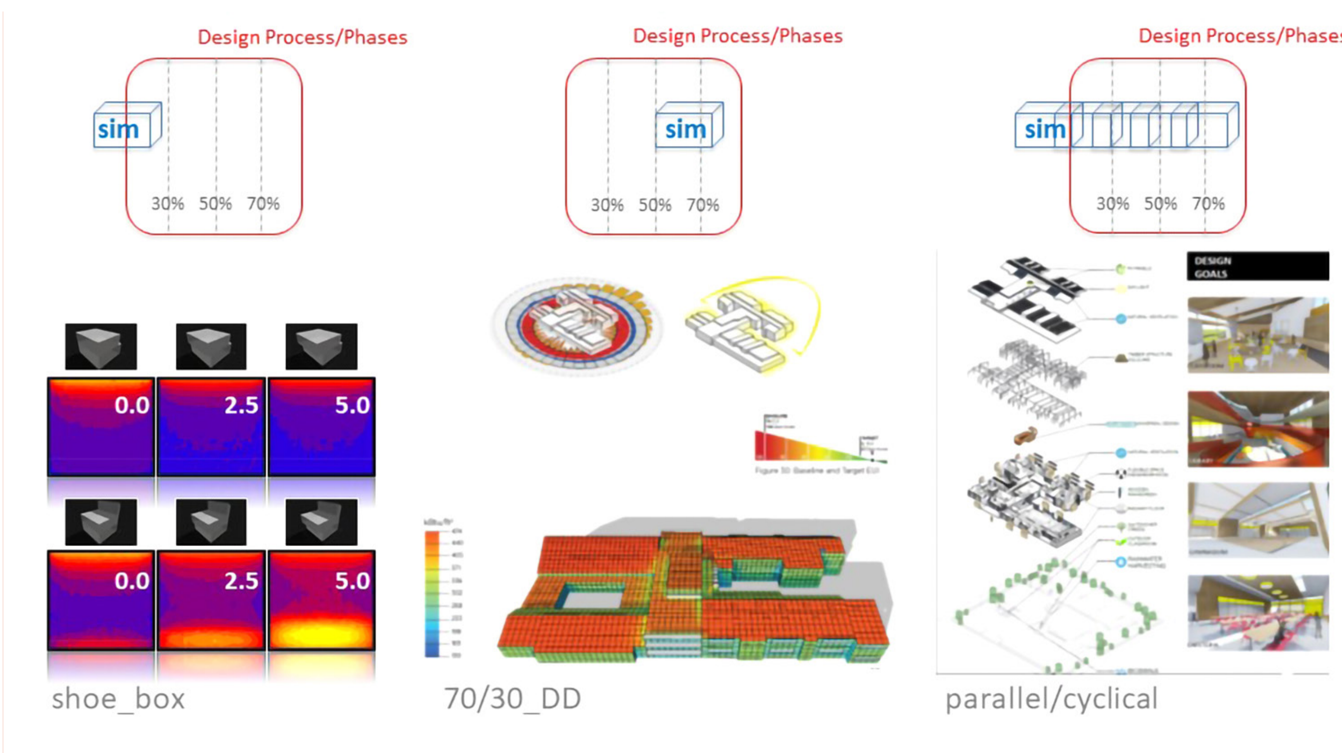


Figure 1. Models of Integrating Simulation in the Design Process

phases of the project. The remainder 30% development of the design phase of the project would benefit from a more complete analysis based on real design inputs of the schematic design of the building.

Because simulation work starts after schematic design, this approach inherently does not allow for exploring basic design decisions such as form, orientation, and massing; which can greatly influence building energy performance. The 70/30 approach is specifically effective for projects when there are strict limitations to these basic decisions, which render them outside the scope of building simulations. Compared to the shoebox approach, a higher level of understanding of energy-efficient design is needed to generate schematic design without the shoebox energy simulations.

3.3 Cyclical Parallel Approach

This approach begins at the project inception and utilizes simple, easily manipulated, performance modeling throughout project design and delivery. It engages energy and environmental conditions modeling and simulation directly with design generation, thus informing major design decisions and providing continuous feedback. Continuous and iterative modeling throughout all stages of the design process optimizes energy efficiency, solar shading, daylighting, ventilation, and, ultimately, the comfort, health and well-being of the occupants.

In this approach, design, performance and energy/environmental modeling are conceived as iterative processes. They can occur in parallel tracks or in cyclical combined tracks (Figure 1). Initial models address fundamental design parameters, including the orientation, site bioclimatic design, building envelope, and massing, typically without including mechanical or electrical systems in a manner that provides crucial, and sometimes surprising, design guidance. As models develop, they provide feedback to the design team on how the form, daylighting systems, programmatic strategies, and other variables will likely affect the project's building performance in terms of energy, daylighting, comfort, and other design characteristics. As the design develops further, the simulation becomes more refined and more informed, leading to predictive performance, details, and more accurate outcomes.

## 4. APPLICATIONS OF WORKFLOW MODELS IN FIVE PILOT STUDIOS

4.1 Building Typology Shoebox: Green Classroom Toolbox™

In this intermediate design studio, students were tasked with designing or retrofitting an existing elementary school to achieve a 70% reduction in energy use than a baseline school in Portland, Oregon – ASHRAE Climate Zone 4C. The studio started with an energy and carbon performance charrette for the first week of studio. Energy analysis computer simulations were conducted for twenty different envelope and school massing strategies on the classroom level using a classroom shoebox model. These simulations were run using Integrated Environmental Solutions Virtual Environments™ (IES_VE) ApacheSim module. The simulations were conducted on 6, two-story prototypical elementary school building in Portland, OR. Students in the studio were divided into six groups, each representing a school typology, and challenged with the goal of developing energy conservation and carbon reduction strategies for one school and classroom typology. For experimental purposes, all best practices were compared to a base case model using one geographic climate location, Portland, OR (45.12⍰ North Latitude, 123.22⍰ West Longitude and elevation of 357 ft).

At the beginning of the second week of studio, student teams presented their findings to the class and developed a guideline booklet documenting successful energy reduction strategies for their assigned school typology. The students were given a choice to implement either the typology they researched during the energy and simulation charrette or any other school typology for their school design. The rest of the design process followed the regular studio sequence of developing specific site analysis, planning, schematic design, design development, and final presentations. At each phase of the design process, the students needed to make reference to the energy and carbon shoebox model guidelines and how their current design is balancing spatial requirements and spatial qualities with energy and carbon reduction goals (Figure 2).

4.2 The Shoebox Approach in 'Environmental Systems' Course

The shoebox approach was implemented in an 'Environmental Systems' course that was coordinated with ongoing design studio projects. This approach was particularly useful for students with minimal to no prior knowledge in building systems. Specifically, because students can easily model and use a simplified geometry of their design, or part of it, and default inputs according to regional and national standards such as ASHRAE 90.1 -2013, or the International Energy Conservation Code (IECC). By starting with code minimum requirements as inputs, students develop an understanding of these codes and ways to exceed them. Another success for this shoebox approach is due to its simplicity. Typically, in early design and schematic phases, a lot of time and effort are spent on articulating building form, often with no input from energy simulation. Using this approach, it allows the students to focus on performative aspects regardless of aesthetics and spatial qualities.

4.3 Evidence-Based Design Development Studio: COTE Top 10 Competition

In this thesis-based two-term design studio, students employed a research-based design exploration of a building type of their choice to be developed on a multi-use waterfront site. The studio started with a master planning effort in groups and


Figure 2. The Green Classroom Toolbox™ Studio – Shoebox model analysis board. Credits: Mathew Linn & Kelsey McWilliams.

evidence-based design decision to choose best orientation and massing for their building based on rules of thumbs, ASHRAE energy design guidelines, and simple calculators, such as COMFEN and MIT Building Advisor. At the end of the first term students developed a complete schematic design proposal and a complete energy model that's ready for simulation and analysis. During the second term of the studio, students conducted multiple simulations runs on the energy model to further refine their studio scheme. At 70% complete design development stage, students conducted a comprehensive simulations of energy, solar loads, ventilation, daylighting, and water performance of their building and used this information to further refine their design for the final submission. The final presentations boards were modeled after the COTE top 10 submission requirements. Two of the students followed-up and submitted their final designs for the COTE Top 10 competition for 2015-2016 and won two out of the top 10 awards of the competition (Figure 3).

4.4 Iterative Parallel Approach in 'Environmental Systems' Course

The use of the parallel approach in design studio requires more effort and time, compared to the other two approaches, it can be challenging to maintain a balanced workflow between simulations and design decisions. To help facilitate this workflow, in-class 'simulation games' were planned to help students compete to achieve building performance goals, e.g. lowering the energy use intensity (EUI) or producing more energy using a photovoltaic system (Figure 4).

4.5 Cyclical Parallel Model Studio: Race to Zero DOE Competition

A parallel simulation/design track approach was employed in an intermediate studio following the Department of Energy (DOE) Race to Zero competition requirements of an elementary school. To be able to employ a full simulation support throughout the design phase, the studio students were grouped into teams of 2-3 students per project. Team members held roles of Designer, Space Planner, and Sustainability Consultant respectively. Each week the team roles changed so as to allow students to experience and contribute to each of these roles. This ensured that each week modelling and simulations of integrated design parameters were tested and appropriately applied to the project design. The simulation started with a shoebox model, then followed by weekly BPS sessions of topical investigations to inform massing, site design, transportation energy expenditure, solar control, daylighting, ventilation strategies, structural analysis, energy use conservation, water harvesting and conservation, envelope design, and life cycle analysis and materials choices. A full whole building simulation analysis for energy and carbon use was conducted at the conclusion of the studio to inform the final production of the design development phase and presentation. The studio presented an ideal case for applying the parallel/cyclical workflow model. Among the difficulties of applying this model were group/team dynamics problems, time constraints between testing the implications of design ideas in simulation and cycling-back to modify and make informed changes to the design, modelling limitations, as well as knowledge gaps of engineering systems that are too detailed for architectural students.

## 5. ACSA COTE TOP 10 STUDENT COMPETITION ANALYSIS

Winning entries of the ACSA COTE Top Ten competition for students were analyzed to better understand the role of building performance simulation in design studios. Specifically, a content analysis procedure was conducted on the winning entries of the past five years (2015 through 2019) to uncover any simulation work or results such as energy use and daylight metrics that are reported and displayed in a way to guide the design process. While it is unclear which workflow was used in these entries, we found simulations and performance metrics in about 70% of those entries. The remaining 30% relied more on general rules of thumb and climate analysis. Interestingly, in recent years (2018 and 2019) more than 50% of the winning entries did not demonstrate the use of building performance simulations on their boards or narrative submissions for any stage of their studio design.

Regarding simulation types, a wide range of simulations were conducted including energy use, daylight, glare, air flow, solar radiation, heat flow, carbon emissions, and renewable energy generation potential. Each of these stimulation types seem to fit certain workflows. For example, solar radiation and heat flow simulations requiring detailed building form and construction assemblies were typically performed in the design development phase following the 70/30 DD workflow. Although three models of workflows can support energy simulations, providing different levels of details at different phases, little evidence support the

Figure 3. The Regenerative Engine, COTE Top 10 student winner design analysis board (Credits: Robert Larson)

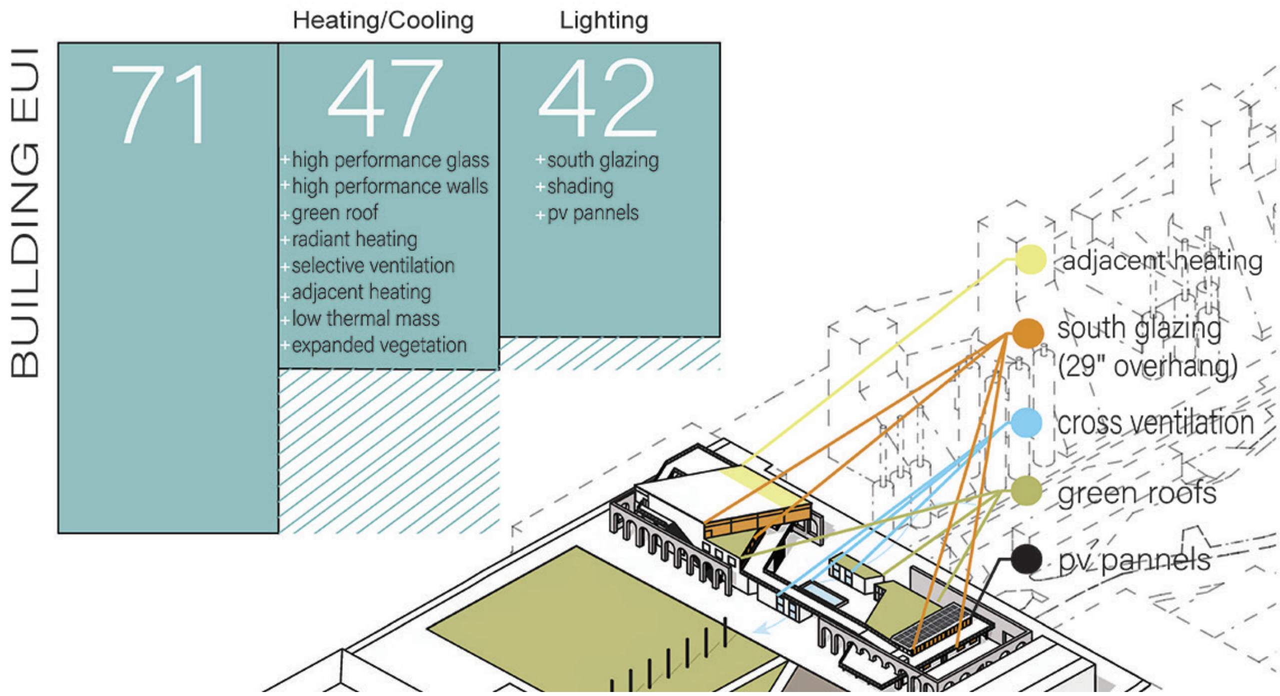


Figure 4. Application of the parallel simulation approach. (Credits: Vito Barraco).

application of the parallel/cyclical workflow in the COTE top 10 winning entries. Common simulation software included easy to use software such as Sefaira, Autodesk Insights 360, and Diva for Rhino. Generally, a large portion of entries included climatic data, such as Psychrometric chart from Climate Consultant software, suggesting that rules of thumb were commonly used in early design phases.

## 6. FUTURE DEVELOPMENTS: BRIDGING THE GAP

Building modelling and simulation workflows are increasingly being utilized in architectural design studios to guide and inform architectural students and professionals' design process and offer them evidence-based feedback on their proposed building performance. Despite the availability of other approaches to integrating technical knowledge and sustainability in architectural education, such as the second studio (Allen, 1997), the design studio approach is still the most valid at raising awareness and providing a hands-on engaged teaching pedagogy and is a favored method for teaching sustainable design by both students and educators (Altomonte, 2009). The paper presented three types of common workflows that were tested in design studios as well as a complementary course that ran parallel to the design studio. It might be concluded that the three workflows can develop successful results of integrating BPS in design studios (Elzeyadi, 2016).

Currently there are numerous software packages available for environmental building simulations. These simulation packages are not created equal. It is important to note that the choice of simulation software package is closely related to the type of workflow employed. Some simulation packages are limited to the shoebox approach, while others are too complex that require more developed design such as the 70/30 DD or Parallel/Cyclical approaches (Figure 5). It should be noted that it is possible to combine and embed the different workflows, such as the case tested in one of the studios presented where the studio started with a shoebox workflow and then switched to the 70/30 DD approach later in the course. It is important to also note the value of applying rules of thumbs, simple performance calculators, and design guides to inform the design decision earlier in the studio. This could save valuable time and iterations of using simulation programs. In addition it provides intuitive and engaged pedagogical approach of learning rather than relying solely on a simulation program to provide all the answers. Finally, it is important to have a good understanding of building science knowledge from required courses refreshed and translated to the students in design terms in studio to allow proper input of parameters required for BPS (Figure 5). The adage "garbage in, garbage out (GIGO)" in computing applies to BPS outputs in the design studio. It is important to watch for many mistakes in modeling and over simplifying simulation inputs to produce untrustworthy outputs. In addition, limitations of some "low-resolution" software in simplifying BPS inputs can lead to less sensitive results and "fake" prophecies.

A survey of the American Institute of Architects Committee on the Environment (AIA COTE) Top 10 student award recipients over the last five years revealed a declining use and integration of BPS workflows in the winning entries projects, especially in the last two years. This is a critical finding as the AIA COTE Top 10 competition can be seen as a catalyst for increasing integration of technical knowledge in the design studio. Both

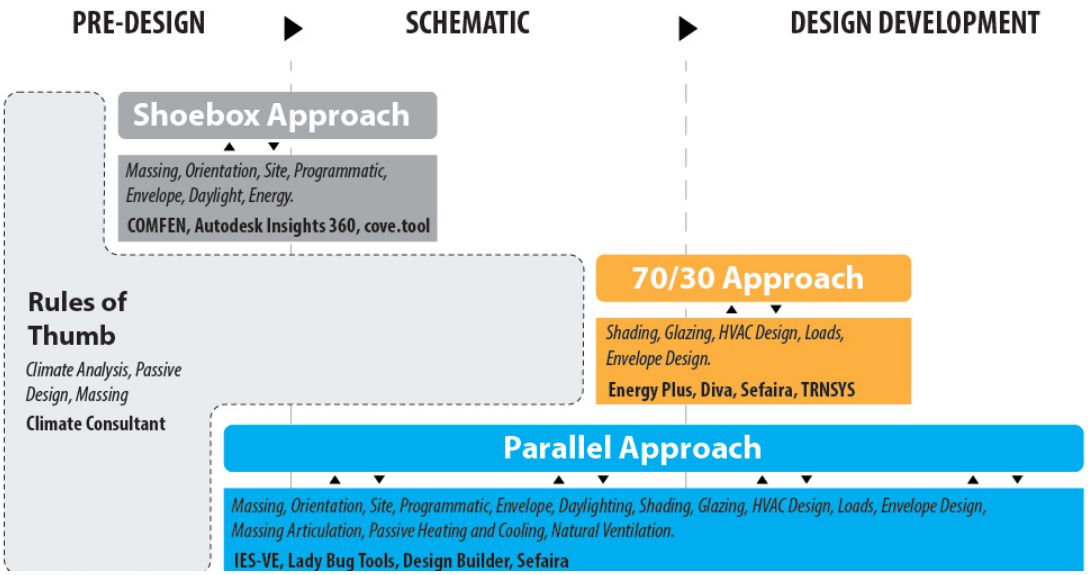


Figure 5. The three simulation integration approaches, typical parameters, and software

students and professionals/academics look for these winning projects as exemplary integrated building designs to aspire to. It is important to require some level of integration of simulation and technical knowledge in the competition rules to ensure students and educators develop competencies in methods and workflows of integrating technical and BPS knowledge in the design studio. It is not the intention of this paper to promote technical integration of knowledge over the merit of good spatial design. On the contrary, the hope is to bridge the gap between the building parametric design and simulation with the design studio creative process for a more integrated design outcome.

## REFERENCES

AIA. 2019a. “2020 COTE Top Ten.” https://www.acsa-arch.org/programs-events/competitions/2020-cote-top-ten-for-students/program.

AIA. 2019b. “Architect’s Guide to Building Performance. Integrating Performance Simulation in the Design Process.”

Allen, Edward. 1997. “Second Studio: A Model for Technical Teaching.” *Journal of Architectural Education*. https://doi.org/10.1080/10464883.1997.10734756.

Altomonte, Sergio. 2009. “Environmental Education for Sustainable Architecture.” *Review of European Studies* 1 (2): 12. doi:10.5539/res.v1n2p12.

Azari, Rahman, and Ian Caine. 2017. “Applying Performative Tools in the Academic Design Studio: A Systemic Pedagogical Approach.” In *ARCC 2017: Architecture of Complexity*, 38–46.

Charles, Patrick P., and Charles R. Thomas. 2009. “Building Performance Simulation in Undergraduate Multidisciplinary Education: Learning from an Architecture and Engineering Collaboration.” In IBPSA 2009 - International Building Performance Simulation Association 2009.

Demirbilek, Nu, Lindy Osborne, Glenda Caldwell, and Oya Demirbilek. 2010. “‘I’m a Designer, Get Me out of Tech Class!’: Closing the Gap between Design and Technology Education.” In The 44th Annual Conference of the Australian and New Zealand Architectural Science Association.

Dogan, Timur, and Christoph Reinhart. 2013. “Automated Conversion of Architectural Massing Models into Thermal ‘Shoebox’ Models.” In Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association.

Elzeyadi, Ihab. 2016. “Green Classroom Toolbox™: Adapting Schools and Students for Climate Change through Sustainable Architecture.” In Sustainable Built Environment - SBE 16 Cairo Proceedings, November 29-December 1, 2016, Cairo, Egypt.

Göçer, Özgür, and Sokol Dervishi. 2015. “The Use of Building Performance Simulation Tools in Undergraduate Program Course Training.” In 14th International Conference of IBPSA - Building Simulation 2015, BS 2015, Conference Proceedings.

Grover, Robert, Stephen Emmitt, and Alex Copping. 2019. “Reflecting on Sustainability: Coproducing a Critical Framework for Sustainable Design in the Architectural Studio.” *Higher Education Pedagogies* 4 (1): 41–63, doi:10.1080/23752696.2019.1624589.

Guy, Simon, and Graham Farmer. 2001. “Reinterpreting Sustainable Architecture: The Place of Technology.” *Journal of Architectural Education* 54 (3): 140–148.

McClean, D. 2009. “Embedding Learner Independence in Architecture Education: Reconsidering Design Studio Pedagogy.” PhD diss., Robert Gordon University, Aberdeen.

McIntyre, A., N. Chatzopoulos, A. Politi, and J. Roz. 2007.”Participatory Action Research: Collective Reflections on Gender, Culture, and Language. *Teaching and Teacher Education* 23 (5): 748–56.

NCARB. 2012. “2012 NCARB Practice Analysis of Architecture.”