Integrated Design Studio Utilizing a Multi-disciplinary Design Team

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ABSTRACT
The Architectural Engineering Department at The University of Wyoming (UW) has designed its undergraduate curriculum to focus on building technology, energy efficiency, and interdisciplinary design. Five years ago UW decided that the design studios should be completed using building information modeling (BIM). Last year the program started leveraging BIM models for whole-building simulation and building performance analysis. This year we took one step further to integrate an Architectural Design Studio with an Advanced HVAC course for a multidisciplinary integrated design experience.

The intent of this paper is to document the recent efforts undertaken by The University of Wyoming's Architectural Engineering program to implement Integrated Design in an attempt to discover and then teach the technical processes of designing a building for optimized performance.

Keywords: *Integrated Design, Multidisciplinary, Energy Modeling, Environmental Analysis, Building Information Modeling (BIM), Architecture Education, Engineering Education*

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1 INTRODUCTION

It is imperative for Architecture and Engineering programs to explore methods of teaching Integrated Design due to the rapidity of change in professional practice. Clients today are demanding a level of energy efficient design that most practicing architects are incapable of fully delivering, which has prompted a recent thinking that the early design teams need to reshuffle members and restructure fees and responsibilities. Design teams are now more often going after projects as joint Architecture/Engineering teams in an effort to bring more energy expertise into early decision-making. But for all its talk, the design profession is having a difficult time implementing Integrated Design.

The problem in the industry is partially a sociological one (making teams collaborate), so part of our challenge is to simulate the sociological aspect in an academic setting. Simply teaching high performance building design can be approached very technically, as with teaching any skill (such

as playing the violin), but to prepare students for the profession, they need to learn both technical and team-working skills. In this, the age of BIM and sustainability, preparing students for the profession also means preparing them to upwards mentor in the areas of green building and applied software skills. But to excel as leaders in the profession, we feel that they should be able to do more—they they should be able to successfully integrate iterative analysis into the design process.

There are few existing models in academia, despite the fact that ABET and NAAB accreditation requirements demand that students work collaboratively in multidisciplinary design teams (ABET 2007; NAAB 2009). One program reported success when pairing architecture students with visiting engineering professionals (Boniface2009). Others have described projects where architecture students 'role-play' as planners, landscape architects, etc. (Angulo and Velasco 2007). Our institution has previously explored long-distance collaboration between architecture and engineering students (Hedges et. al. 2009).

This study concludes that continued exploration and implementation is needed, both in the approach of teaching technical skills and in forming multidisciplinary team structures and workflows. Despite successful experiences, we are undecided whether to focus on multidisciplinary teamwork, or on teaching high performance design to all disciplines with the assumption that anyone could be designing buildings in the near future.

2 INTEGRATED DESIGN PROCESS

The use of the phrase Integrated Design in the industry can either refer to a holistic approach towards design which involves experts from many disciplines weighing in early, or alternatively, to a design collaboration between the architect and the mechanical systems engineer which leans heavily on iterative simulation as a means of achieving high performance design. While we wish to simulate both conditions in the classroom, we understand that students are not yet experts in their discipline; therefore, the intent of the Integrated Design course for us is to teach high performance design strategies through the use of iterative simulation.

Creating a multidisciplinary studio has understandable challenges, and so we believe it is reasonable to also use Integrated Design to describe the use of a combination of "architectural" software programs with "engineering" analysis programs, though ideally you would have an engineer at least reviewing the analysis. Other experimental Integrated Design studios have also celebrated the combined use of design and analysis software as critical factors in their success (Rashed-Ali, et. al. 2010). While mentioning software tools, it is worth noting that a crucial step in this process, both for academic and professional projects, is the utilization of building information modeling rather than more generalized 3D geometry modelers. With a BIM based design process the live model can always reflect the latest design, enabling analysis iterations to be conducted quickly and efficiently.

2.1 Types of Analysis

Traditionally when people talk of simulation software, many focus entirely on energy modeling, paying little attention to daylighting analysis, solar analysis, computational fluid dynamics

(CFD), and detailed heat transfer. We have come to understand that there are many problems with an over-reliance on energy modeling in the evaluation of building performance. First of all the energy model oversimplifies the effects of daylighting, airflow, solar gain, and heat transfer on energy consumption, particularly where the design addresses these issues at a high level of detail. As an example, daylighting analysis tools have long since reached a higher level of sophistication then the earlier daylight factor methods still found in many energy modeling programs (Reinhart and Jones 2004). Second, when evaluating discomfort the traditional energy model does not adequately evaluate issues related to airflow, glare, or solar radiation, nor does it graphically display problematic results in a way that is meaningful to the designer.

Furthermore, the margin for error with energy modeling can be very great due to the uncertainty of many parameters, while the margin of error for detailed environmental analysis can be much lower as a result of fewer parameters and highly accurate geometry. Consequently, the most effective design analysis process requires a combination of environmental analysis using detailed building geometry, and energy modeling using a simplified model (Gardzelewski 2010). This relationship is most evident in simulation programs such as Integrated Environmental Analysis (IES) and Design Builder, where detailed environmental analysis results can directly affect the energy simulation, and vice versa. By contrast, less sophisticated programs often substitute simplified algorithms for detailed calculation methods.

While every simulation program has different capabilities and methods, we can think of the optimal process as one having cyclical iterations between energy modeling and other types of detailed environmental analysis, happening at least once in every stage of design (figure 1). Between the stages in this cyclical process, there is the opportunity for many more iterations of environmental analysis, particularly if the designer is using analysis as part of his/her design process (e.g. designing the optimal size and shape for a light shelf).

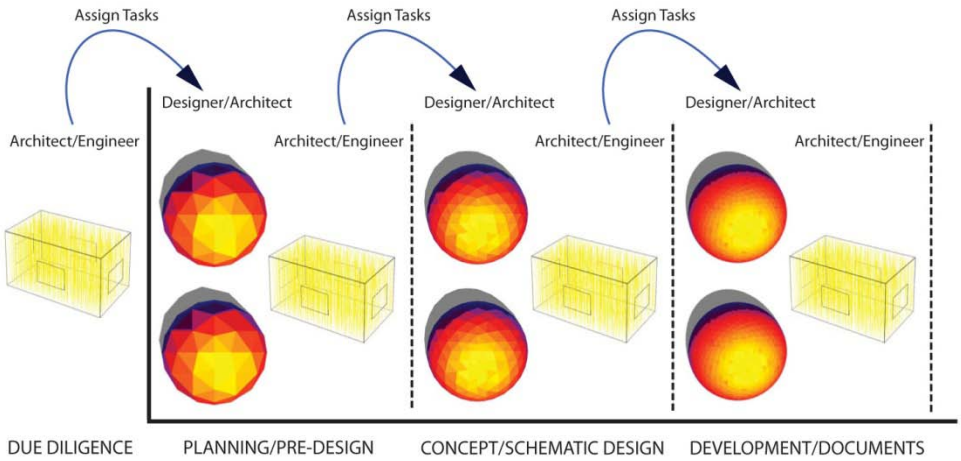


Figure 1: Multidisciplinary Integrated Design process

Taking things a step further, if the design team is conducting their own energy modeling there is the potential for many more energy modeling iterations. Generally the architects steer away from energy modeling out of the fear that they will not achieve accurate results or that the client will not trust their results. However, those who undertake energy modeling find it particularly useful in the crucial planning stages, where a building form can be designed to optimize energy saving strategies such as passive solar, daylight harvesting, natural ventilation, etc. This level of sophistication is the hallmark of 'best practices' in industry (Becerik-Gerberand and Kensek 2010) as well as a goal for undergraduate education.

2.2 Levels of Integrated Design

As previously mentioned, successful Integrated Design in practice usually involves active design analysis by both the architect and the engineer, however there are many different methods in which design analysis is currently being implemented.

- **Iterative Analysis**—analysis can be performed as an isolated exercise, or in iterations, either driving the iterations or being used in a comparative manner. While we prefer not to see the isolated exercise, this often what you get with firms or projects teams that are new to the use of analysis.
- **In-house vs. Multidisciplinary Analysis**—analysis can either be done in-house, or by the building systems engineer as part of a multidisciplinary process.

For the further clarity about how analysis is being used we can split these into four categories:

- **In-house design analysis** is the process where the designer subcontracts out a specific type of analysis as design validation, most often for colorful images to be included with a presentation or a set of deliverables. In this case the designer has an idea that the building will perform well at certain task, which they want to convey graphically to the client.
- **In-house iterative design analysis** is a more rigorous process where the designer has analysis capabilities which he/she utilizes to inform the design decisions. This category also includes the scenario where there is an analysis expert on the design team who the designer works with in optimizing different aspects of the design. With an iterative process, the designer knows that the building will perform well and wants to convey visually the rigorous process that led to this design. There is a strong argument that the final building will perform much better if the design team is doing iterative analysis, but the clients are not yet convinced—after years of seeing Photoshop enhanced make-believe, there is skepticism that the same is being or will be done with analysis results.
- **Multidisciplinary analysis** is the process by which the building systems engineer conducts building simulation and presents the results (usually including systems design alternatives) to the owner and the architect. The advantage of having the engineer conduct the analysis is that they are the ones who typically take most of the responsibility for building performance, so they often have much more expertise translating into more trust in the analysis results.
- **Multidisciplinary iterative analysis** can be done a couple of ways. Energy modeling can come at the very beginning of the project, where each subsequent design iteration is evaluated for energy consumption. An alternative approach is where the mechanical engineer works directly with the owner in coming up with optimal building form and design strategies, setting the design constraints for the architects (a role reversal of sorts). Clients

with a strong commitment towards energy efficiency, particularly net zero, are relying more and more on the engineer's analysis to make the crucial decisions.

As we compare these different methods it becomes evident that an iterative process is far superior, but to make a value comparison between in-house and multidisciplinary analysis is a very serious proposal—it nearly requires one to take a stance on which profession is more qualified to make the design decisions affecting our buildings. Whichever direction the industry goes tomorrow, it is clear today that designers need better analysis skills and engineers need better design skills.

3 CASE STUDIES

3.1 Academic Case Study: In-house Analysis

For students to develop analysis software skills they need practice. An easy way to do this is to require a list of simulations that they must present with their design projects. The process of running a simulation forces the student to learn the parameters affecting the results, and how the results translate into building performance metrics. Ideally, students trained in this process will see analysis as an integral and instrumental part of architectural design; not an optional or supplemental function.

Simply requiring analysis unfortunately does very little to ensure that a design will perform well. Students will fix noticeable problems, such as rooms without any daylight, but if analysis is only required at the end, most students will not actually incorporate it into their design process.

With a single simulation it is also common that students will run the wrong type of analysis. But if they are required to improve their designs, then they have to pay more attention to what they are evaluating to determine how they can improve upon it.

3.2 Academic Case Study: In-house Iterative Analysis

To ensure that students utilize analysis to improve their designs we developed what we call the Integrated Energy Design project (figures 2 through 4). This project starts with the analysis of an existing building or a new building design. After the initial analysis, students must demonstrate improvement through before and after studies. Specifically, the students are given the following design requirements:

- Build a base energy model, or, carefully study climate, building type, and existing utility bills to determine the best possible energy saving strategies.
- Through design, increase the solar gains during the heating months and reduce the solar gain during the cooling months. Quantify the gains and reductions in solar energy.
- Through design, provide all occupiable spaces with adequate usable daylight. Show how you will reduce glare where direct sunlight enters the space.
- Through design, reduce the total glazing on non-south facing facades while meeting all other objectives.
- To the extent of your abilities, determine the energy savings for the new scheme.

Figure 2: Original vs. Proposed designs including before and after analysis (Joel Helenbolt)

Figure 3: Original vs. Proposed designs including before and after analysis (Amanda Hansen)

Figure 4: Proposed design including before and after daylight analysis (Doug Fankell)

3.3 Academic Case Study: Multidisciplinary Analysis

In an on-going integrated, multidisciplinary design studio, we have paired a design studio with an advanced HVAC course, with the two classes working together on the same project; the renovation and expansion of an existing library. While an existing building requires a slightly different analysis process than new construction, as a project type it is becoming much more common in the current industry. In organizing this studio we have matched the number of HVAC students with the number of design teams so that each separate scheme has a dedicated "engineer."

The HVAC class first creates an energy model for the existing building, which is calibrated using recent gas and electricity bills. The calibrated energy model is then used to evaluate retrofit options such as replacing windows, adding insulation, and replacing the mechanical equipment. The engineers then explore slightly more aggressive strategies, such as the addition of skylights, atriums, or active facades, and the results from these studies are used to set the guidelines for the renovation and expansion of the existing building…

3.4 Academic Case Study: Multidisciplinary Iterative Analysis

At some point before the mid-term review of the same project, the "architects" will take the design lead, and the "engineers" will have to update their energy models to reflect the current designs.

The immediate challenge is in developing a schedule for iterations, and defining the roles and responsibilities of the team members—very similar to the challenges of a real project. The most difficult challenge from the instructor's (project managers) perspective is in knowing how to reasonably determine the appropriate number of design and analysis iterations, and with it the quantity of effort and the quality of the design. This again parallels the real world, where credit hours and the grade can be thought of as a substitute for fees, and the number of design iterations may very well be limited by the student's desire to only do work that they feel they are contractually obligated to do. Unlike a real project, however, we cannot simply increase the scope or extend the deadline, so if the course expectations are greater than what can reasonably be accomplished, the process may fall short of its mission. We expect to see a very energetic process, fueled by excitement and the scientific rigor of discovering an optimal design. We will also be eager to see if power struggles arise between the architects and engineers.

3.5 A New Breed

In an architectural engineering program, many students feel strongly that they should be able to practice both architectural design and engineering simultaneously. On occasion, these students will be unusually motivated to pursue iterative design analysis. One example (figure 5) shows the optimal building form for an office building in Laramie Wyoming, derived from exhaustive analysis iterations, with thoughtful consideration on how form can influence various green design strategies. In another example (figures 6 and 7) the challenge of designing a net zero building is met through rigorous analysis, including PV calculations, wind power studies, even a bio-inspired trombe wall-variant that collects 40% more solar energy while providing excellent daylight. These kinds of outstanding efforts provide a model for future aspirations.

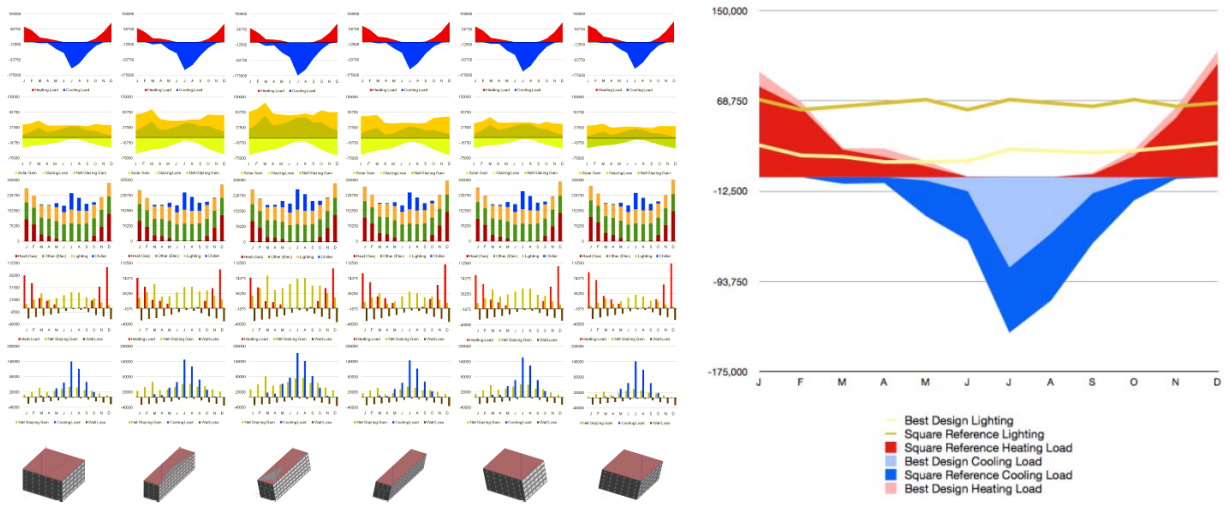
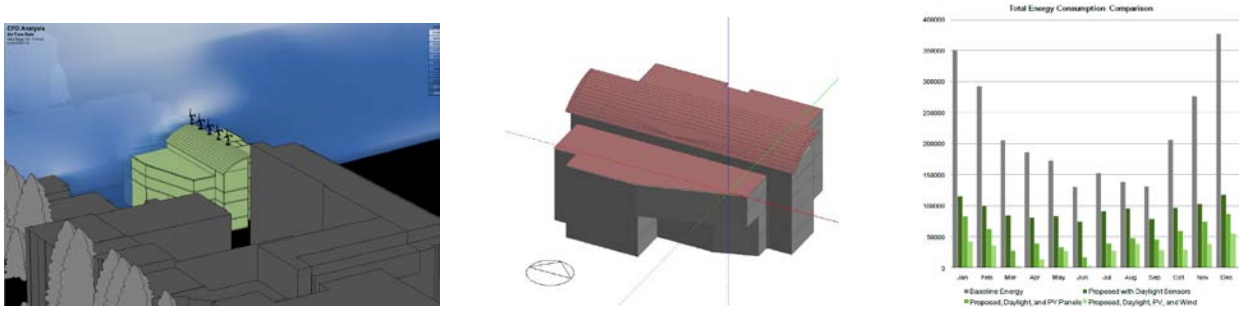


Figure 5: Building Form Energy Analysis (Ryan Meyer)



a) CFD analysis b) Energy simulation model c) Iterative results

Figure 6: Examples of iterative analysis in the design studio (Ryan Meyer and Trent McAteer)

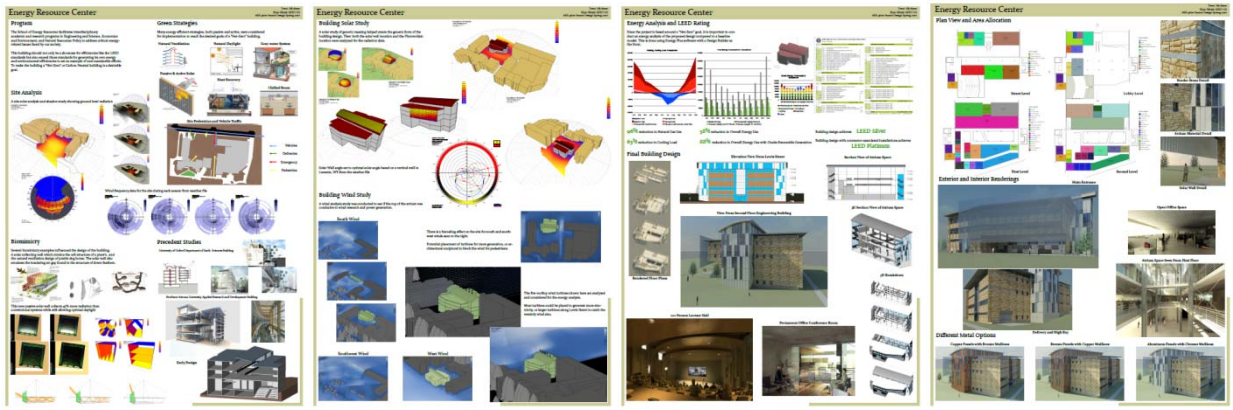


Figure 7: Example final presentation boards (Ryan Meyer and Trent McAteer)

4 CONCLUSIONS

Having experimented in the last couple of years with various levels of Integrated Design in the classroom, it is clear that students benefit from employing iterative analysis in an architectural design process, though time is taken away from other aspects of 'design'. A similar study has concluded that integrating simulation tools "requires a change from the traditional studio format (Rashed-Ali, et. al. 2010)." One might argue that a global shift towards sustainability in the design studio happened long ago, but that the practical methods of achieving this are only beginning to be explored. While methods of teaching design studio will always be debated, our own experiences point towards iterative analysis as an unrivaled teaching tool for understanding building performance and energy use.

We are not yet ready to make any hard conclusions about which specific types of Integrated Design are most successful in the classroom. As a necessity the students must be working in a BIM environment. From here it is clear that success depends on the incorporation of analysis into the design process, where a gauge of success is often the number of analysis iterations and their consistency throughout the project. It is a challenge to structure a design courses to require analysis iterations, however, doing so is an unmistakable benefit to the students and to the program as a whole.

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