Design for Quantitative and Qualitative Performance: A Pedagogical Approach for Integrating Environmental Analysis into the Early Stages of the Design Process

JUINTOW LIN
California State Polytechnic University, Pomona

INTRODUCTION

In recent years numerous new sustainable analysis design tools have become accessible to architectural designers, and while the learning curves may be much shorter than with past computational tools, it presents us with several new challenges. These new computational design tools for environmental analysis are constantly evolving and demand simultaneously specialized and generalized knowledge. One of the most difficult issues confronting architectural students who wish to incorporate sustainable principles of design lies in understanding what are the most appropriate tools to use and how to effectively integrate them into the design process.

There is a critical link between design tools and design heuristics and it is therefore vital to make transparent the possibilities and limitations of design tools for students specifically as they relate to issues of sustainability. The design process must be equally transitional and malleable in order to be efficient and intelligent with both the choice of tools and their use for students of architectural design. Architects can make a significant difference in the hugely important issue of global warming, and educators can make an important impact on this problem by fostering future generations of designers to both understand the importance of this issue and have the ability to design informed creative solutions.

This paper summarizes a professional elective seminar that addresses two key problems that currently afflict sustainable design approaches within the context of architectural education including, 1) that students often make design decisions based on what they intuit, but are lacking either the technical skills or time to validate their assumptions, and 2) that sustainable options are not appropriately used or used disjointedly without being thoughtfully integrated into the design process, thereby missing potential synergies.

COURSEWORK

In the *Tools for Sustainability* professional elective seminar, architectural design students explore the integration of a wide palate of computational tools to successfully consider sustainability in their designs. Students learn, implement and evaluate various environmental assessment tools for low-energy building design. The course provides a practical overview of both the tools and methodologies for incorporating sustainable principles into the design process. Students are introduced to a number of computational tools that range in usefulness, from the gathering of data, to energy simulation and visualization.

The course is primarily for 4^{th} and 5^{th} year undergraduate as well as 2^{nd} and 3^{rd} year graduate students. All of the students have taken the two required Environmental Controls class prior to taking this seminar. The class meets for two hours twice a week, for a total of 10 weeks. The course was taught first in 2006 and then again in 2007. At the time of writing, the course is in its third year (2009).

There are three goals in the course: 1) To use analytic inquiry as a means to evaluate design, 2) To learn a sustainable design approach or methodology, and 3) To foster the continuation and dissemination of the course outside of the classroom by means of an online forum.

A focus of the course is to integrate computation and design instruction to comparatively and explicitly understand both the usefulness of the tools and the heuristics. To achieve this, a common design project served a means to integrate and validate sustainable strategies. The computational tools are used to validate assumptions about when and how to best integrate the most appropriate strategies. Students work on a relatively simple design project that serves to interrelate each specific design issue. They verify and test their assumptions at all stages of design, continually refining the design, for a whole-building approach.

Analytical Inquiry

The course provides both an analytical skill-set to make informed intuitions, and a pedagogical approach to integrating sustainable options synergistically. Intuition with respect to environmentally responsible design is derived from learned experience that can be enforced not only through real world experience, but also by computational simulations and calculations. The course teaches students to develop informed intuitions through analytic inquiry, as well as means to address strategies for interrelating sustainable options so that they work together.

Students are often taught concepts of environmental controls in the classroom, which little opportunity to test the validity of their assumptions. For example, they may be taught to size an overhang based on summer and winter sun angles, which are incidents that happen at a single moment in time, for example June 21 @ noon. However, an optimal shading device geometry that considers all the times of the year can be determined by modeling it and testing it for all times of a typical year (in 6 to 60 minute increments, depending on the software). More often than expected, analysis results differ from original assumptions; for example anticipated shading benefits are superseded by lower passive solar heat gain results. An important aspect of the course is to clearly understand why intuitive assumptions differ from actual simulated results and to iteratively find optimal results within the process.

Through verification of design strategies with the

Figure 1 – Screenshot of Software reviews

use of software tools at all stages of design, student projects are designed to reduce environmental impacts of development. With the use of energy analysis software (such as HEED, Ecotect, IES VE-Ware and VE-Toolkit, Building Energy Calculator, and Radiance), students learn to make the most of passive and active sustainable systems. They can test envelope assemblies, effects of infiltration and internal loads, as well as building geometry design options such as fenestration layout, shading designs, and building massing. Renewable energy systems are also examined, sized, and a payback period is calculated. Beyond this, students continue the iterative design process by designing for adequate daylighting and the reduction of glare through the use of simulation software such as Radiance. Life-cycle analysis of materials is also examined using simple software programs such as BEES.

Online forum

In an effort to disseminate the findings of the students' experiences with the software, an online forum, *www.toolsforsustinability.com*, was created for the use of the students as well as the greater architectural community. Here, students post reviews of software (Figure 1), review books, blog about upcoming events or sustainable topics, and add weblinks related to computational environmental analysis tools. In addition, course documents, including syllabus, schedule, grades, and all assignments are online to facilitate paperless learning. The forum deals with technical issues as well as design processes and methodologies. The site has seen substantial growth in traffic since it was started in Fall of 2006 and was featured in the article, "Top 100 Architecture Blogs". The site has 1600+ registered users at the time of this writing.

Students therefore not only have the opportunity to network with their peers, but also access the larger community of architects and designers interested in sustainable analysis design tools. The available resources and reviews provide a critical database for making informed decisions about what specific computational design tools to use as well as when and how to use them based on the experience from the course.

DESIGN METHODOLOGY

Throughout the course of developing a project, students learn the steps and tools that facilitate a holistic, iterative design process. An example of such a process might typically incorporate the following steps: 1) understand project requirements; 2) analyze site and climatic conditions, examine psychrometric chart, research passive strategies for specified climate zone, and formulate preliminary design priorities; 3) conduct preliminary site design which considers issues such as storm-water runoff, urban heat island effect, topography, and building orientation; 4) conduct preliminary architectural design incorporating passive and active sustainable strategies; 5) evaluate geometry options using detailed energy simulation; 6) examine wall/floor/roof assemblies and; 7) size plug loads and designing a renewable energy system; and 8) select green products that contribute to better indoor air quality and reduce environmental impact.

In addition to the goal that students learn available software products, it was also important that students became familiar with a clear design methodology for sustainable design. While there are many methods or approaches appropriate for sustainable design, the methodology in this course uses a number of discrete steps that necessarily incorporate analysis for an iterative approach. Students are taught these skills and can exercise variants to this methodology depending on future projects. Students come out of the course with a base design methodology of discrete steps incorporating analysis into the process for achieving sustainable projects. The methodology is summarized below:

Analysis of Site, Program, and Climate As part of the analysis, students perform a climate and site analysis that includes identification of weather files, reviewing the psychrometric chart, prevailing winds and wind speeds, sun angles, and available solar radiation. In addition to analog methods, such as finding tables, etc., students are taught to use Weather Tool, Climate Consultant, and IES VE-Toolkit (Figure 2).

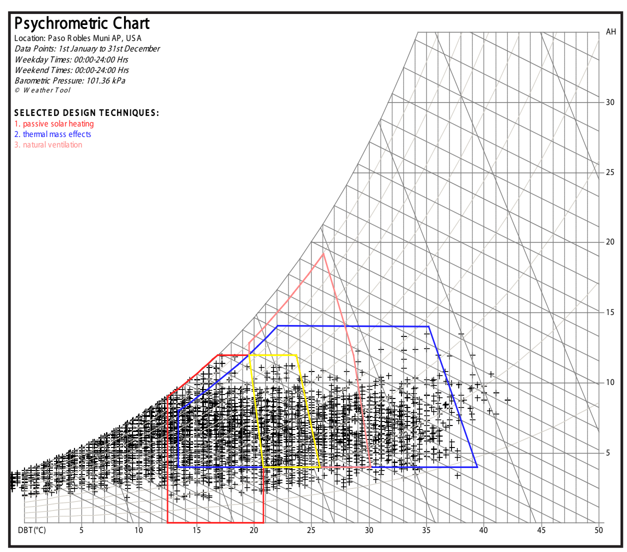

Figure 2 – Psychrometric chart showing passive heating strategies. Passive solar heating is outlined in red thermal mass in blue and natural ventilation in pink. The comfort zone is outlined in yellow. (Source: Weather Tool)

Research Appropriate Strategies and Determine Design Priorities Based on the climate analysis above and also by looking in reference books, students evaluate the passive strategies available and appropriate for the project. For example, one can use the Passive Design Analysis feature in Weather Tool and see the impact of each or a combination of passive strategies on discomfort hours, which is often proportional to energy loads. If students are interested in pursuing LEED certification, then they are also encouraged to fill out the appropriate checklist and identify areas which most affect schematic design.

It is not practical to utilize all sustainable strategies that may be beneficial to the project. Students therefore need to evaluate their research and the project goals to determine which strategies should be pursued. A list of design priorities is compiled based on research and continues to be edited throughout the quarter.

Preliminary Design Before beginning design, it's important that students understand the ramifications of preliminary design ideas on a building. For example, orientation can make a fundamental difference which affects many future design decisions. Building Energy Calculator and HEED are utilized to find optimal orientation as well as optimized percentages of window-wall area and insulation values. From here, students revise design priorities as needed and commence architectural design. The initial design then serves as the "base case", which is used for comparative testing in the rest of the quarter.

Testing and Modification of Design The majority of the course is an iterative design process between design, modeling, and testing. Students are taught to use HEED, Ecotect, Winair, Radiance, IES VE-Ware/Toolkit and Excel in order to evaluate their designs for thermal performance, shading design, daylighting levels, and natural ventilation (Figure 3).

Students learn to model their designs in the appropriate program, and afterward evaluate the model to understand which strategies should be tested. For example, one can look at individual thermal zones and identify times of day or times of year where the zones are particularly uncomfortable (Figure 4). With this information, one can work to improve these conditions.

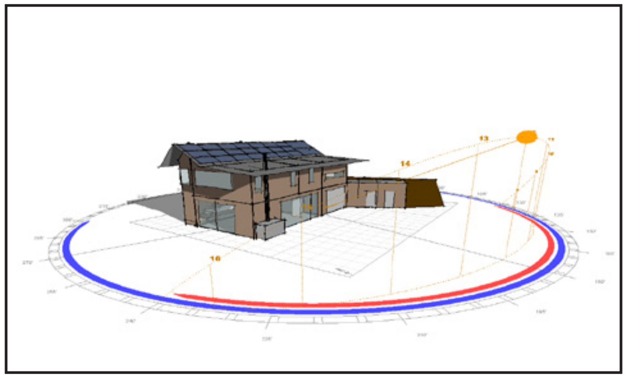

Figure 3 - Model showing sun shadows on December 21 @ 12:00PM (Source: Ecotect)

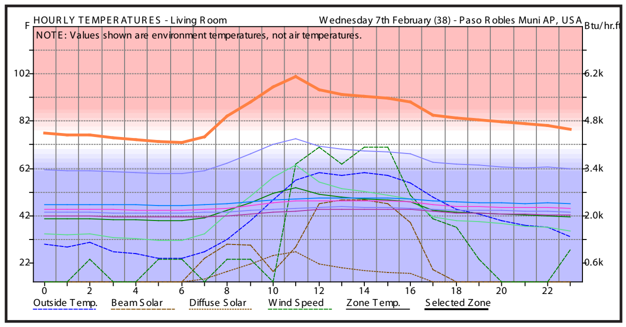

Figure 4 – Estimated Hourly Temperatures on the peak coldest day, with living room shown in orange (Source: Ecotect)

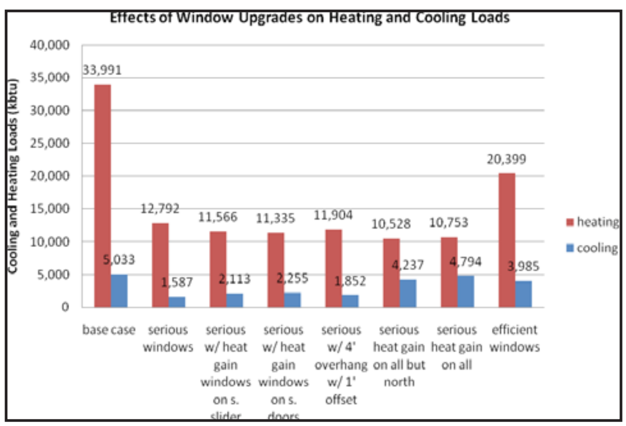

Figure 5 – Effects of Window Type on Total Heating and Cooling Loads. (Source: HEED/Excel)

Next, the design process evolves to include the building geometry; items such as overhangs, window sizes/location, ceiling height, are simulated and tested. In parallel to the geometry testing, simulations are carried out for non-geometry design upgrades, such as wall assemblies, roof assemblies, slab insulation, window specifications, and the use of insulating blinds. Data is exported to Excel for ease of analyzing data. Graphs are created to compare these single-upgrade tests for each category (Figure 5).

The inclusive list of strategies is then summarized into a simple table which not only indicates how upgrades affect the annual heating and cooling loads but also ranks them according to specific priorities. (Table 1). Students use this list to study a series of combined upgrades, which in turn is used to make decisions on the final designs.

Not present in this list but something I would like to explore in future iterations of this course is to include the cost benefits and anticipated return on investment of each upgrade. However, in the context of a 10-week course, this may not be realistic.

Other peripheral aspects of sustainability are also examined in parallel to the simulations discussed above, and the design is subsequently modified. These include life cycle cost of materials using BEES, further evaluation of the LEED checklist, sizing of renewable energy systems and water recycling systems.

LESSONS LEARNED

The pedagogical approach outlined above fosters a specific approach to several critical issues related to the repositioning of analysis within the early stages of the design process. A central concern is understanding which is the most appropriate level within the architectural curriculum for introducing digital analysis and simulation tools. Secondly, which are the most appropriate tools to use, and thirdly, how to effectively integrate particular tools into the early design process? The approach described in this paper is a discrete one which is intended to be a malleable template that can evolve for specific design projects and that can easily incorporate new software for analysis. The lessons learned are outlined in the sections that follow.

upgrade	**Annual Htg (kbtu)**	**Annual Cool (kbu)**	**Prio-rity**
Base case	33,991	5,033	
serious windows	12,792	1,587	***
above w/ heat gain windows on s. sliding door	11,566	2,113	*
above w/ heat gain windows on s. doors	11,335	2,255	*
above w/ 4’ overhang w/ 1’ offset	11,904	1,852	*
serious windows heat gain on all but north	10,528	4,237	
serious windows heat gain on all	10,753	4,794	
efficient windows	20,399	3,985	**
reduce south overhang to 2’	33,754	5,253	
reduce south overhang to 3’	33,873	5,157	
add 4’ overhang to lower south doors	34,839	4,323	
add 4’ overhang to lower south and west	34,960	4,004	
add 2’ overhang to lower south doors	34,839	4,323	
add 2’ fin to south side of west door	34,039	5,002	
R5.5 light blinds on windows (accessible)	28,964	2,897	**
R5.5 light blinds on windows/doors (accessible)	23,630	2,897	***
R5.5 dark blinds on windows (accessible)	28,459	4,305	

Table 1 - Base Case improvements Table shows the priorities and effects of strategies on Annual Heating and Cooling Loads

Website Dissemination

Allowing the architectural community to view the student work from this course is mutually beneficial. The dissemination uniquely benefits the architectural community by allowing them to view the design process that the students undertake.

This process is valuable because, often in practice, there is not adequate time or financial resources for detailed climate and energy analysis for each project. Also, these types of tasks are often given to engineers or energy consultants. In addition, the students benefit from sharing their results because they feel they are part of a larger community of architects and designers with shared interests. This allows them to exhibit additional pride in their assignments, often tailoring the content to other viewers in addition to the instructor. With this said, there is still no substitution for in-class discussions and team work. This cooperation and relationship is still vital to the learning process.

A great benefit of the forum created for this course is that students are quite active in posting their opinions with fewer reservations. Part of the forum includes a blog with various categories. Under the Education category, for instance, students answered a question regarding when tools should be introduced. The majority of students said that they would be overwhelmed should energy simulation courses take in the 1st or 2nd years. On the other hand, a small minority of the students thought early instruction could be useful because the visual learning method of energy modeling and simulation helps to also reinforce the core sustainable concepts.

Such comments are very valuable not only for future iterations of the course but serve as a valuable means of candid dissemination to the greater academic and professional community. Based on feedback from the online forum by students in the course, it could be summarized that the second half of the second year of a student's design education is an appropriate time to introduce general sustainable concepts. Third year can evolve these concepts to integrate practical and contextual issues of design related to a project, and computational tools should be introduced in the fourth year, and cultivated in the 5th year, so that there is time for individual heuristics to evolve through the implementation of a malleable pedagogical approach relative to a number of design studio projects.

Teaching Methodology

In the first year of this course, students evaluated case study buildings such as the VDL House by Richard Neutra and the King's Road House by Rudolph Schindler (2006). In the following year (2007), students evaluated and made recommendations for designs produced by students in a topic studio for a faculty housing project on campus (to be built and subject to measurement and verification). However, students were hesitant to make serious design changes on projects that were not their own. In the third year of this course (2009), the focus has been shifted from evaluating existing designs to a method where students evaluate their own designs.

This has resulted in a clear improvement in the quality of work. There has always been a gap in the acquisition of analysis knowledge compared to the application of this knowledge and when there is a stronger attachment to the problem/project the students tend to have a better understanding of the sustainable issues and a more clear idea of the value of analysis. They are encouraged to integrate but not supersede design issues with building performance. Sometimes the best design is not the one with optimal performance but one that has integrated performance and design.

To date, the seminar format for the course has worked well. The projects are often quite small and there is enough time to go through a great deal of material. In the first two iterations of this course, a portion of class time was devoted to lecturing on sustainable principles. This year, more time is being spent on tools instruction. Principles are reviewed as needed in the context of the tools instruction. This decision was made in part from comments made on the toolsforsustainability blog. Most students who replied preferred that more time be designated for tools instruction. It should be noted however, that the knowledge of general sustainable principles should not be undervalued. It is preferable if the students have this base knowledge as a. The students in this course have had two - three classes in Environmental Controls, and it is assumed that future students will understand these concepts coming in.

A larger objective of this research is to see more tools instruction integrated into the regular design studio. The best level is in design studio at the level of for 4th and 5th year students who have a better idea of their specific interests. There is a particular subset of students who are interested in technical issues in addition to aesthetic design. In these instances, these students would benefit from taking a studio which mixed design and computational tools. This is also advantageous because it's important to work on multiple projects with software tools, based on a personal design project that is much more inclusive of other design issues. For example, when students learn BIM, it may not be difficult from a technical standpoint, but when it is applied to a personal design project, it necessarily introduces a completely new pedagogical approach that may be disruptive and inefficient unless there is a high level of proficiency with the software. Students will not typically apply a new approach to their design processes unless they are totally comfortable with the computational strategies.

Challenges

The largest challenge met by students was problems with the software programs. Several of the programs are free or distributed at a very low cost and often do not have a quality technical support system in place. With all new software there are bugs which invariably cause frustration and affect efficient time management.

Software Programs

One of the primary benefits of the course and website is to garner feedback from students regarding the software programs. Outlined below are select summaries of lessons learned particular to a few of the various software programs used and evaluated within the context of the course.

Weather Tool and Climate Consultant Both of these programs are free for students and are used at the beginning of the design process for climate analysis. Although the two programs do differ in terms of how they represent the data, they both essentially provide graphic formats to view information in weather files. Both programs are easy to use and require little background education on environmental principles. Therefore both programs can be taught starting in the 2nd year. It is in fact quite useful to supplement a preliminary introduction to environmental issues with the software because students are able easily navigate around the software without constantly referencing data in a textbook.

HEED (Home Energy Efficient Design) The results from this software in the context of this course were very good on many levels. Firstly it is free, quick to install, and is not resource intensive. It can quickly compare results in an easy to interpret manner. You can display up to nine schemes next to each other, including two automatically generated ones that include a code-compliant and an energy-efficient design. One can quickly see the affect of the wall R-value, window specifications, and orientation on anticipated energy costs. For advanced users, there is some customization allowed, but not as much as some of the other programs. It can't model complicated buildings and is best used for homes. Despite the ease of format, it is recommended that students compile their information from the software in Excel for better clarity.

IES VE-Ware and IES VE-Toolkit Integrated Environmental Solutions has several software suites including VE-Ware and VE-Toolkit. Both of these programs require the use of SketchUp, Revit, or similar to export gbxml format to IES <Virtual Environment>, the fully-function energy simulation program. VE-Ware is free for all users and provides and analysis of the building energy consumption based on building design and general assumptions based on building parameters set. These values are compared to the national average and to the 2030 Challenge targets. Students are asked to iteratively make changes and test the design to approach or meet that target. VE-Toolkit has more advanced features than VE-Ware and is available at a student rate of $100/annual license. These include climate analysis, suggestions of design strategies based on building design and climate conditions, water assessment and analyses of water recycling strategies, daylight factor simulation, detailed energy and carbon simulations, as well as comfort information such as room temperatures and PPD (percentage of people dissatisfied. The reports generated are graphically clear and provide ample background information as well as recommendations.

Autodesk Ecotect Analysis 2010 For more detailed analysis, students also perform energy studies in Ecotect. This allows them to go into more detail with their design. The modeler in this program is quite different from others that students are used to. Therefore, it is necessary to devote adequate time to familiarizing oneself with the interface and the tools within Ecotect. A nice feature is that the results are nearly immediate (similar to HEED and IES VE Suites) and are easy to interpret in a graphical manner. It is important for students to see such immediate results so that design modifications can be readily incorporated into an iterative process. The program is extremely inclusive in terms of its capabilities. One is able to perform detailed studies on thermal analysis, solar radiation, visual access, acoustics, lighting levels, carbon emissions, photovoltaic matching, and much more. It is also fully customizable, allowing one to create materials and schedules for appliances/ occupants. It is an excellent program with great potential that is free for both students and faculty.

BEES This is also a free program which is used to perform a preliminary life cycle analysis for various materials specified within a building. It is very easy to use and produces easy-to-understand graphs. Students can use the software to further appreciate the environmental (and economic) impact resulting from the selection of materials. A downside to this software is that it is very limited in terms of the materials available (currently only 230) BEES provides an introduction to the concept of life-cycle assessment but does not include enough materials currently to make informed decisions.

Closing Remarks

This paper summarizes work that addresses two key problems of sustainable design approaches within the context of architectural education including, 1) that students often make design decisions based on what they intuit, but are lacking either the technical skills or time to validate their assumptions 2) that sustainable options are not appropriately used or used disjointedly without being thoughtfully integrated into the design process, thereby missing potential synergies. In this paper, a pedagogical approach is outlined which fosters a specific approach to several critical issues related to repositioning of analysis within the early stages of the design process. The approach described in this paper is a discrete one which is intended to be a malleable template that can evolve for specific design projects and that can easily incorporate new software for analysis. There is a critical link between design tools and design heuristics and the hope is that the results from this course will help to make transparent the possibilities and limitations of design tools for students specifically as they relate to issues of sustainability.

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