Simulation Space

A new Design Environment for Architects

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Abstract. It is the attempt here to test simulation tools in relation to a design process and speculate on strategies to not just integrate simulation tools in the design process but to use these tools to construct a new design environment for the architect.

Keywords. BIM, building information modeling, performance, simulation.

Introduction

The built environment has the largest impact on the natural environment. In the United States for instance buildings account for 39% on energy consumption and are with 39% the largest contributor of all carbon dioxide (CO2) emissions. The architect can take responsibility in this matter; become an ambassador for building environmentally friendly by designing and suggesting environmentally friendly buildings.

It is therefore important to provide tools for the architect to respond to these issues. Architects typically rely on the input of outside experts to determine the energy performance of a building, which usually slows down the design process down and hurt the final design. Due to more powerful and more accessible simulation tools this situation is about to change. To meet the responsibility to build environmentally friendly the design environment has to change. It is the attempt here, not just integrate simulation tools in the design process but use these tools to construct a new design environment for the architect. A survey will be used to select simulation tools that might be of interest, situate these tools in a design process and link them in order to construct a new design environment.

A new responsibility

As any artist the architect has a responsibility to the interiority of his discipline. A composer for instance has a responsibility through composing a piece of music to contribute to the development of music as a poet has a responsibility through writing a book to contribute to the development of literature. Different to other art disciplines an architect also has accountability towards a client since there is a budget and a function and a responsibility towards a larger community especially when the client is not the only user of the building. Since architecture has an impact on the natural environment there is a responsibility that has been left out of the discourse that needs to be equally recognized in the design process of a building, a tension field of competing responsibilities.
The architect’s environment

Air, land, sunlight and countless other physical influence create an extremely complex environment for a building. It is possible to generate a virtual model and run the simulation to get an accurate feedback about the building's performance. It is possible to build a very accurate and complete virtual model of the building and perform an energy simulation. The problem with this approach is that the digital model that is required for that simulation would have to be developed on a level of detail that usually happens at a very late state in the design process. Material decisions would have to be made and details would have to be solved. This kind calculation is a necessary check before you build the building but is because of its complexity not a helpful feedback in an early stage in a design process when we only have a small sketch model for instance.

The design environment of the architect is characterized by different media the architect use to design. Physical or digital models, renderings and drawings provide immediate visual feedback and inform each other by moving quickly between different media such as different software packages. Different media are useful at different stages in a design process. Small sketch models might be useful to study the relationship between form and program distribution for instance. To respond to this environment tools that highly visual and interactive, that allow for easy import and export and that provide feedback on different levels of sophistication become necessary.

Simulation tools

Based on the criteria of the described design environment four tools were tested: Ecotect, Energy-10, Sketch-Up and eQuest. To be able to compare Interoperability, graphical interface, simulation method and simulation output and interface a 20’ cube was constructed. To evaluate the tools in the context of a design process the analysis will be structures in three parts: Input, output and a summary. In the first part the types of information that need to be entered for the analysis, the capacity of handling geometric complexity and the correlation of formats with other CAD programs will be evaluated. In the second part the method and the simulation output will be analyzed and related to its appropriateness for different phases in a design process. The sophistication of communicating feedback will be evaluated.

Energy-10

Energy-10 is a simulation tool that was developed specifically for smaller buildings, less than 10,000 square feet and no more than two thermal zones. The software was developed in collaboration between the Sustainable Buildings Industry Council (SBIC), the National Renewable Energy Laboratory (NREL), the Lawrence Berkeley National Lab (LBNL), and the Berkeley Solar Group.
**Input**

There is no graphical interface in which the design is actually drawn. The geometry is assumed to be rectangular and the shape of the building is controlled by entering the square footage and a ratio of length to width. Weather data, utility rates, building use and HAVC systems are also entered on the initial screen for each new project. Information on the construction types and thermal properties of walls, floor and ceiling can be entered through a series of data cells and pull down menus. (Figure 1) Custom assemblies and material can be created easily with data input cells.

**Output**

The simulation capabilities of Energy-10 are very robust. Utilizing the California Non Residential Engine (CNE) it performs an 8760 hour, energy balanced simulation. In addition to running the calculations on the building attributes input by the user, it will run a second simulation that finds a value within the initial model that, if improved, will reduce energy usage, and analyzes a second iteration with an optimum parameter set for that attribute. This immediately gives the designer an understanding of where their design can be improved and the impact of these improvements. (Figure 1) Energy-10 can also assess the impact of delighting on lighting power loads and heat gain and incorporate solar technology as a contributor to reduced energy consumption. After the analysis is complete, the first screen displayed is the data sheet. The building construction is summarized and system types and set points are listed. The systems are sized based on the analysis. The results of the energy analysis are given in the amount of energy consumed, both for gas and electric, and as cost, based on the utility information provided on the first screen.

Additional output is available in the form of graphs that can display highly specific performance characteristics, including a breakdown of energy use by function, comparing the two simulated models (figure 1) and the daily energy use for heating and cooling along with the outside and inside temperature. While this information can provide critical insight into the performance of the design, these graphs are also helpful in vetting the integrity of the model. In addition to the side-by-side comparison of iterations Energy-10 allows for the optimization of design through a process known as elimination parametric. The effects of one factor in the buildings
performance (insulation, glazing, internal gains) are “eliminated” from the model by setting its contributing value ridiculously high or low to see how it effects energy use. For instance, to see if conduction losses are a primary contributor to heating and cooling loads, a parametric run is done with the R-value of all walls and ceiling set to 1000. The difference in energy consumption between this model and the base case are compared to see the effect. This is done for several attributes, lighting loads, occupancy, U-values of glazing, and the results are mapped against each other. The actions that produce the most significant changes indicate that tweaking those attributes with realistic values in the base model will have the greatest effect, giving the designer great insight on where to focus their design efforts for energy reduction.

**Summary**

The limitations of building size, number of zones and few HVAC system options narrow the application of Energy-10 to the simplest of building types, or only allow the tool to be utilized at the earliest stages of design to develop envelope strategies without the complexities of modeling more advanced HVAC options. The ability to incorporate daylight strategies and model the effects of renewable technologies on energy use provide significant help in the design of high performance buildings. Its lack of a visual representation of the modeled design may be discour age some designers, but at the same time simplifies the entry of geometry and physical construction, reducing the learning curve and time spent building the model since the material properties would have to be input for a graphically represented model as well. Energy-10’s data output is extremely accurate and can be parsed for specific performance characteristics and its presentation is clear. Clearly it is a tool that in the very early phase of a design process can show how initial design moves affect energy performance.

**eQUEST**

eQUEST is a graphical interface to the DOE-2 analysis engine, which is one of the most robust simulation tools available. It can be used to demonstrate compliance with California Title 24 and ASHRAE 90.1 standards for building performance. As such, it has become a standard of performance analysis for projects pursuing LEED certification. It is similar to Energy-10 in its interface and methodology, but does not have the limitations on size and complexity. Because it has been developed with a combination of public funding and backing from California utility companies, eQUEST is available for free, and is continuously being updated to incorporate new systems and strategies for building design.
Input

The geometry of the building can be modeled as designed, although it helps to simplify the model as much as possible for analysis. System zoning and controls sequences can be highly refined and there are a variety of system types available to simulate. Other features include the ability to perform daylighting calculations and link these to lighting controls to determine energy savings. eQUEST also offers the ability to perform batch simulations incorporating multiple parameters for aspects of the building envelope and system design, called Energy Efficiency Measures, to analyze ‘what-if’ scenarios. Batch processing allows for the iteration to run automatically Energy-10 which requires the parameters to be manually changed, re-simulated and reported.

eQUEST offers three stages of model development. Beginning with the Schematic Design wizard, information about building use, location and utility rates are entered though a series of drop down menus and data fields, similar to Energy-10. The building footprint and zoning can also be developed by tracing an imported dxf file. Each window in the wizard asks for different input of building functions. While it is called the Schematic Design Wizard, the level of detail requested in each field seems to suggest that eQUEST is best started after some consultation with the project’s engineers. The next phase is the Design Development Wizard, which expands the number of system types available and allows for the modification of schedules and more detailed input of envelope information and controls set points. The third phase of building a model in eQUEST is through the Detailed Interface. This gives the modeler access to every aspect of each component in the model and allows for fine-tuning the inputs to make the simulation as accurate as possible. For the nature of this analysis, only the schematic design wizard was utilized, accepting several default values through the process.

Output

For graphic representation the model’s construction needs to be extremely simplified. The graphics are poor, and the geometric representation should be kept simple, the output is very sophisticated and dense of information such as charts and graphs on total annual electric, gas consumption, daylight levels in sky lit spaces and static pressures for every air handling units for instance. While the cube exercise does not exploit this, in a building with dozens of stories...
of systems, and multiple zones within each system, this becomes a tool that allows a knowledgeable designer, working in conjunction with a good engineer to create a highly refined design in terms of energy efficiency.

Summary
eQUEST is the benchmark for whole building simulation. The results are very reliable. While it claims to be an easy to use design tool, the complexity of the tool requires knowledge of building systems and performance characteristics that an architect might not have. The program was for our research study too complex and requires a highly defined design.

Sketch-Up / Demeter

Sketch-Up is a 3-d modeling tool that is easy to use and, with some of its advanced functions disabled, freely available from Google. It is effective for initial visualization and conceptual studies as well as communicating design intentions to clients and consultants. It also has a broad network of users, connected through 3dWarehouse, a web site in which models and techniques are freely exchanged. Its use as an analysis tool has been limited to shadow studies with the professional version, until the recent beta release of Demeter, a plug-in that links Sketch-Up with Green Building Studio’s online analysis tool. GBS is a web-based application that uses DOE2.2 (the same engine utilized by eQUEST) to perform full year energy analysis. Utilizing its proprietary gbXML file format, Green Building Studio interfaces also interfaces with Revit and Archicad for design file input. Results can be exported to Doe-2, eQUEST, Energy+ and Trane700 energy modeling tools for more intensive analysis. (Figure 9)

This figure, form Green Building Studio’s website highlights the perceived disconnect between the act of design and of performance analysis that I feel is the most significant contributor to the design professions restricted ability to address performance issues.

Input

The modeling process in Sketch-Up for performance analysis is not very different than the beginning step of building a typical design/visualization model. As with eQUEST, the key is to keep the model very simple, using single planes to represent walls and windows, and clearly delineating spaces for zoning.

The actual preparation of the model for analysis occurs entirely in Demeter, which is run on top of Sketch-Up. The user defines zones and occupancies through the selection of surfaces. Then each surface is identified as to whether it is interior or exterior and if is a wall, floor or ceiling, window or door. No material specifications can be made beyond this and it is not clear what the default materials are. After assigning all materials the model is exported to Green Building Studio’s online simulation engine for analysis where location data is chosen before the simulation is processed by a GBS server.
**Output**

Because the simulation is run on a remote machine, the results are delivered via e-mail. The output from the analysis includes the total annual use and cost. In addition to kWh, and MJ (mega joules) energy consumption is measured in Hummers. The lifetime use is also provided, which is valuable for life cycle cost analysis of efficiency strategies. An additional piece of information shows the source of the electric power.

With the base subscription though, much of the information GBS can provide is not available. While the first few simulation runs are free, GBS charges for additional iterations of the model by the space being modeled.

**Summary**

Though it seems promising to link a freely available modeling tool with a well proven and powerful simulation engine, the results of the Sketch-Up/ Demeter analysis do not provide designers with enough information to evaluate the performance of their designs and make clear decisions on the best strategies to improve performance. The inability to edit materials, occupancies and systems coupled with the fees for additional iterations make the process of evaluating multiple strategies difficult, if not impossible. Also, given the fairly quick simulation times of Energy-10 and eQUEST, the need to wait for results to be e-mailed could also be a hindrance to design process.

A solution to these shortcomings may be on the horizon with a plug-in that will allow a Sketch-Up model to be exported, with material definitions, for analysis in Energy Plus. The notion of a feed design tool linked to one of the most powerful simulation tools available is promising, assuming the results can be interpreted intelligently and used effectively.

**ECOTECT**

ECOTECT combines a highly graphical interface with a broad range of analysis tools in a unique way. The types of analysis directly available within the software are shading, shadows and reflections, solar, lighting, thermal, and acoustic. The target audience is architects in the schematic and design development phases.

Packaged with ECOTECT is climate analysis module, Weather Manger, providing clear diagrams of climate information that are derived from several weather file formats. While it performs a multitude of analyses, the thermal, acoustic, day lighting, the calculation methods it utilizes lack sufficient detail for reliable investigation. They may be sufficient for the earliest stages of design, but intensive analysis required for useful design development must be done in other software. ECOTECT addresses this by offering the ability to export to several popular analysis
formats. However specific modeling conventions must be followed for each format type, limiting the ability to move one model freely among different tools. Modeling conventions also required for each analysis also make it difficult for one model to be used for all calculations within the tool as well.

**Input**
The interface of ECOTECT is controlled through a series of tabbed views each with a specific function for setting up, creating, viewing and analyzing the model. The drawing interface, or 3D EDITOR tab, is the most CAD-like of the analysis tools evaluated in this study, with buttons activating commands such as line, plane, and zone, to generate the geometry of the model. This is also where windows, doors and other opening are assigned to surfaces. There is a parent-child relationship between surfaces and the openings that is common in other analysis tools. In ECOTECT this relationship must be explicitly modeled, whereas in Energy-10 and eQUEST, it is automatically generated. When any object is created a default set of material properties is assigned to it. These properties are required for every analysis, and the default types can be changed from a menu of existing material definitions. Custom materials can also be defined by the user, but since ECOTECT uses a thermal calculation method peculiar to England, the Admittance Method, some of the properties required are difficult to obtain for uncommon materials.

The 3D EDITOR tab provides a wireframe view of the model, and this is the only view in which the geometry and object properties can be edited. The VISUALIZE tab displays an OpenGL rendering of the model and is used for most of the analysis of shading, sun-path and sun-penetration. (Figure 11 and 12)

**Output**
While the ease of modeling and access to multiple types of analyses make ECOTECT an attractive tool for designers, the manner in which it displays results is the most valuable feature of the software. Tabulated data can be exported to excel for post-processing. Graphs of data for the various analyses map the information in clear, almost expressive formats. With the analysis grid, discussed in the summary of the DD Ecosystem project, the results of several types of analysis can be displayed in conjunction with the geometry being measured, or represented directly on the surfaces themselves. This also applies to the use of data from some of the third party tool that ECOTECT can generate exports for, most notably Radiance lighting software, which can provide accurate simulation of daylight and artificial lighting. An additional feature is the ability to quickly save the results of all analysis in both of raster (.jpg, .bmp) and vector (.wmf) formats for editing in graphics software. One bug in the current version is the mislabeling and, in some cases, the incorrect conversion of SI units to IP, which requires some diligence on the users part to interpret the results correctly.
Summary
ECOTECT is the closest to a one-tool solution for providing early phase performance analysis to designers. Its ease of input, ability to import several types of geometry, clear graphics, ability to export results for presentation and evaluation, and model information for use in more advanced tools show it to be a suitable starting point for the integration of simulation into the design process. Some aspects of a building design, such as those dealing with shading and solar control can actually be refined to a high level within ECOTECT alone, but many of the analysis methods lack the rigor or rely on overly simple calculations that make it them insufficient for use in final performance design decisions. ECOTECT attempts to address this with the ability to generate several file formats for more complex simulation tools but aside from the Radiance interface for lighting studies, though most require such strict modeling protocols that their use is limited. As a starting point for designers looking to improve building performance from an energy and comfort standpoint, these shortcomings do not outweigh the benefits of the analysis feedback ECOTECT can provide, as long as the designer knows when the limits of the tool have been reached and can turn to more appropriate methods for later phases in a design process.

Conclusion
The development of Building Information Modeling (BIM) software holds the promise of fully integrating analysis abilities within design tools, allowing designers to utilize a model for design and simulation simultaneously but as this analysis shows there are still large problems that hinder the integration of simulation software in a design process.

The analysis shows that the main problems are the level of performance feedback in relation to a specific design phase, the diversity of 3D modeling capacities between programs - for most simulation tools attributes must be provided to assimilate alternative calculations or modeling processes and the separation of analysis tools and design tools.

From the analysis it is clear that there is no tool that can provide an appropriate feedback for all stages of a design process. Also the analysis shows the level at which each program can contribute to different phases of a design process, ensuring the appropriate information is being analyzed and communicated. The diagram below (figure 15) suggests locations of the analyzed tools in a design process, a diagram that can be interpreted as a design environment. (Figure 16)

To be able to design more efficient in this design environment an environment would be needed that provides all modeling capabilities of high end modeling programs, allows for easy transfer of files, gives appropriate feedback for different design phases, manages information in powerful graphic ways and is highly interactive.
Given the immediacy of our global climate situation and the ability of the design profession to make significant contributions toward reducing our impact on climate change, developing such an environment is the urgent need for architects.

References

USGBC, ‘What is Energy-10’.