Integrating Building Energy Simulation in the design process

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Abstract:
To significantly increase building energy performance, the use of building simulation software at the earliest has been emphasized. Inherent complexity in data representation, I/O (Input and Output) and Visualization of available software requires specialist knowledge to leverage the potentials offered. Early stages of design are characterized by unstructured and incomplete data which is insufficient as inputs to software based on detailed representations of the systems in the building. Existing simulation software, developed in research organizations are targeted to be used by building services engineers at detailed stages and does not suit the purposes of design community. This article attempts at identifying the reasons behind unpopularity of simu lation software in the early stages of design and also argues that a new breed of decision support systems is needed for energy efficient building design.

Introduction:
Building regulations, energy labelling, and tax exemption for low-energy buildings - all are contributing towards the increased use of building energy simulation programs in the design process. Based on algorithms - evolved and matured over time, these tools simulate physical properties and behaviour of buildings; provide designers with an indication of performance and help to make informed decisions. To take it a step further, integrated simulation approach considering interactions among all of the building's components and systems are incorporated in the current generation of simulation programs. Benefits offered by these concepts include but not limited to increased energy savings, occupant comfort, and ROI (Return On Investment). Apart from some exemplary projects, these holistic concepts and advanced simulation programs are of little use in the design community.

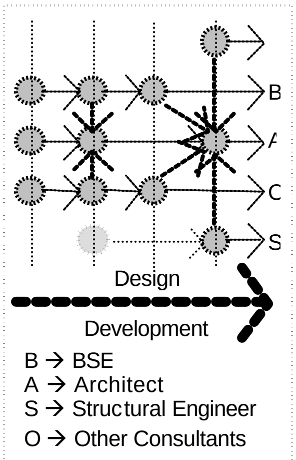

Figure 1: Data flow among design professionals in different stages

Developed mostly in research organizations, building energy simulation programs focus on modelling and simulation than on the integration with the design process. Enormous amount of input processing is required even to simulate of a small subset of the domain. Complicated process to accomplish tasks made their use limited to occasional validation of the proposed idea than to assist in the design development. Extension of the capabilities of simulation software/ UI (User Interface, some simulation software clearly separates engines from interfaces) can play a vital role in early stages of design, in which most of the decisions affecting energy-efficiency of the building are made.

Design process and building simulation
Building design is a sequential decision making process, in which decisions taken at an early stage dictate the properties and behaviour of the building at later stages. Composition of the design team, fragmentation of the process and activities make it unique from other mass-manufactured product design. Although the concept of integrated design and construction has been emphasized, it merely imitates what has been done in the manufacturing industry and focuses more on the product than on the process. Increased complexity due to the technological advancements in materials, construction, and management calls for whole and integrated building simulation at the earliest to guide the decision making process. Early stages of design are characterized by unstructured data, incomplete building information and horizontal data-flow from one stage to another. Figure 1 shows that vertical data-flow increases as design progresses with increased level of collaboration among design professionals. Decision support systems leveraging capabilities of building simulation software can offer help in integrating expertise of different domains in the design process particularly in early stages.

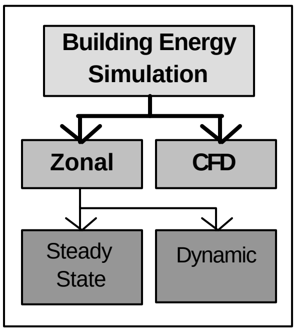

Figure 2: Types of building simulation software

Brief overview: Building Energy Simulation

Computer aided building energy simulation falls into two main categories based on modelling approach: zonal and CFD (Computational Fluid Dynamics). Software (TAS, EnergyPlus, ESPr, DOE etc.) based on zonal modelling approach gives statistical indication of year-round energy performance of the building. To reduce complexity and computation time, these models are simplified where every point in space/ zone is considered to be in similar thermal state. New calculation engines encompassing new features can be implemented into existing infrastructure. Software based on zonal modelling can again be categorized into two: steady-state and dynamic. These tools are limited in capabilities to simulate large single space with spatial differences (Atrium, Lecture hall etc). CFD tools (CFX, Flovent, etc.) are based on the principles of fluid flow and able to represent real-life situations more accurately than their zonal counterparts. 3D space is divided into large number of grids and each node in the grid is assigned an initial value for different environmental parameters. Based on the equations of mass, momentum and enthalpy conservation; assigned values are replaced by solving the equations numerically. Computationally expensive CFD tools require enormous effort in preparing mesh and have limited use in building design.

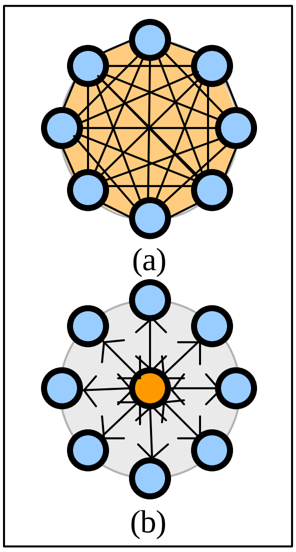

Figure 3: (a) Before, (b) after interoperability

Barriers of integration

Increased computing power and advances in information visualization has enabled simulation software to predict and present performance more accurately than ever before. Some of the barriers still remain in practice preventing effective integration into the design process. Some key points can be summarised as:

- The lack of standardized data representation has led to the slow uptake of computer based simulation techniques in the design process. To overcome this limitation, concept of building product model has been proposed and developed which is essentially a semantic representation of all the elements and processes of building in all lifecycle stages (Eastman 1999). Neutral Data standards eliminate redefinition of data every time an exchange is needed, retain integrity and enhance interoperability among software and stakeholders. Figure 3a shows the existing situation where a large number of translators needed to transfer data among software tools. Figure 3b shows the improvement, where building information is stored in a neutral format (File based, shared repository, and direct software access) reducing semantic loss of data through translation. IFC (Industrial Foundation Classes), a neutral data representation encompassing all lifecycle stages of building has been specified and promoted by IAI (International Alliance for Interoperability) (IAI 2003). Though a handful of software vendors implemented subsets of IFC, its importance in shaping tomorrow's design process has been proved.
- Simulation centric approach in software development has alienated them from the very purpose they have been designed for. Excessive emphasis on the capability of the simulation engine led to poorly designed user interfaces without regard to the design process. Until now, Architects and building services engineers are mostly concerned with the environmental design of buildings. Increasing awareness of lifecycle impact assessment as a concept to enhance sustainability has been expected to require involvement of all the design team members for energy efficient building design. Requirements of this diverse group of professionals need to be incorporated in the next generation of simulation software.
- From users' point of view, computer programs are meant to assist them in conducting day-to-day businesses. Some go further and change the process acting as catalysts. Bulk amount of result generated by simulation programs has no effect on design decisions unless they are processed and unnecessary bits have been eliminated from visualization.
- Applications of formal optimisation methods and artificial intelligence is necessary to find optimum values of parameters where the number of design variables are large and their relationship is complex to understand with a few graphs. Realizing the potentials offered by these techniques isolated sections of building simulation community have recently been focusing their research

on decision making and optimisation. Outcomes of these researches are more of "showcases" than useful products ready to be used by the design community.

Ongoing work

Segregation of simulation engine from user interfaces in initiatives like DOE, EnergyPlus paved the way for efficient interface design targeting certain groups of professionals. Three of the ongoing initiatives are described here.

Papamichael et al. (2001) designed BDA (Building Design Advisor), a software environment that supports the integrated use of multiple analysis and visualization tools throughout the design process. Decision making as part of the design was recognized and implemented. Elements of building are accessed through the Building Browser, while the Decision Desktop allows designers to compare design alternatives with respect to performance indicators addressed by integrated tools. BDA depends on parametric runs of simulations to produce comparison data for making decisions. Depending on the number of parameters $(n > 2)$ and number of steps involved, whole process may take hours of computation time and may become hard to visualize and make decisions.

DAI (Design Analysis Interface), a research project by Georgia Institute of Technology, Carnegie-Mellon University and University of Michigan addresses integration issues from a process context (de Wilde et al. 2002). Emphasis was placed on the workflow between 'scenarios', 'tasks' and 'users'. The objectives of the DAI project are:

- Understanding and implementing the needs of users mainly energy consultants,
- Respecting workflow of the users,
- Development of scenario specific building simulation model interfaces,
- Rapid development of internal data interfaces,
- Tool independent system architecture,
- Support to incremental design analysis cycles,
- User controlled gateway to design information.

A number of projects have been undertaken at ESRU (Energy System Research Unit), University of Strathclyde to investigate the nature of design process, and how building simulation tools can be integrated for delivering better designs. ESPr, zonal-modelling based energy simulation software has been the centre point of ongoing efforts. Without developing new software from bottom-up, capabilities are added in modular fashion to accommodate growing needs. Hand (1998) opted for a project manager type of application which controls all aspects of simulation based design decision support. Citherlet (2001) emphasized on the holistic assessment of building performance based on an integrated simulation approach combining multiple simulation tools into one decision making platform.

All the initiatives described above are similar in their intent and somewhat to the proposed outcome. Decision making and integration into the design process have been emphasized. A closer look at the outcomes of the researches reveals that all opted for decision support systems harnessing capabilities of simulation software for better integration either implicitly or explicitly.

Building Simulation in different lifecycle stages

Contemporary practice involving building simulation applies mostly to detailed design stages and starts with the Building Services Engineer. Figure 4a shows the level of involvement of architect and building services engineers in environmental design during lifecycle stages. Figure 4b shows the relationship of design effort with expected energy savings. It is evident that a bigger amount of energy can be saved by little efforts at the early stages. Figure 4c shows the availability of building energy simulation software in different stages. Lifecycle impact assessment tools encompassing all the stages of the building from inception to demolition/ reuse will play a vital role with the increasing awareness of its importance. They have also been included to ascertain availability. A comparative analysis of the graphs shows that building simulation programs failed to address environmental design in early stages where most energy savings can be made. Building simulation programs are targeted for design development stages, where energy savings almost equal the design effort.

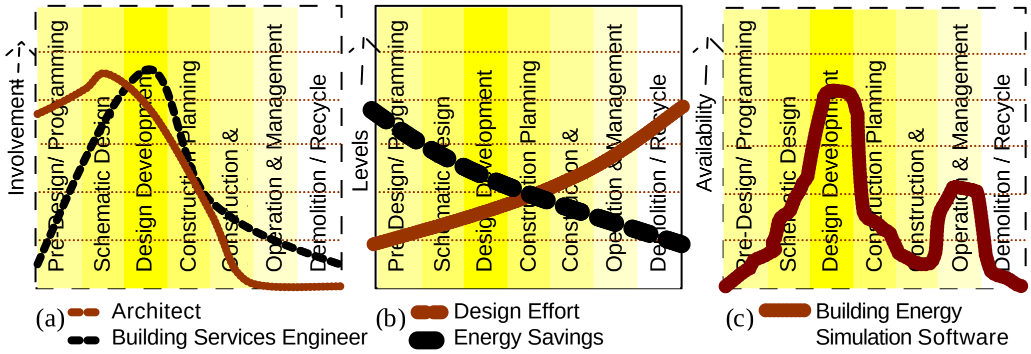

Figure 4: Relationships in different lifecycle stages of the building.
(a) Involvement of Architect and BSE in environmental design (b) Level of Design Effort vs. Energy Savings (c) Availability of Building Simulation Software

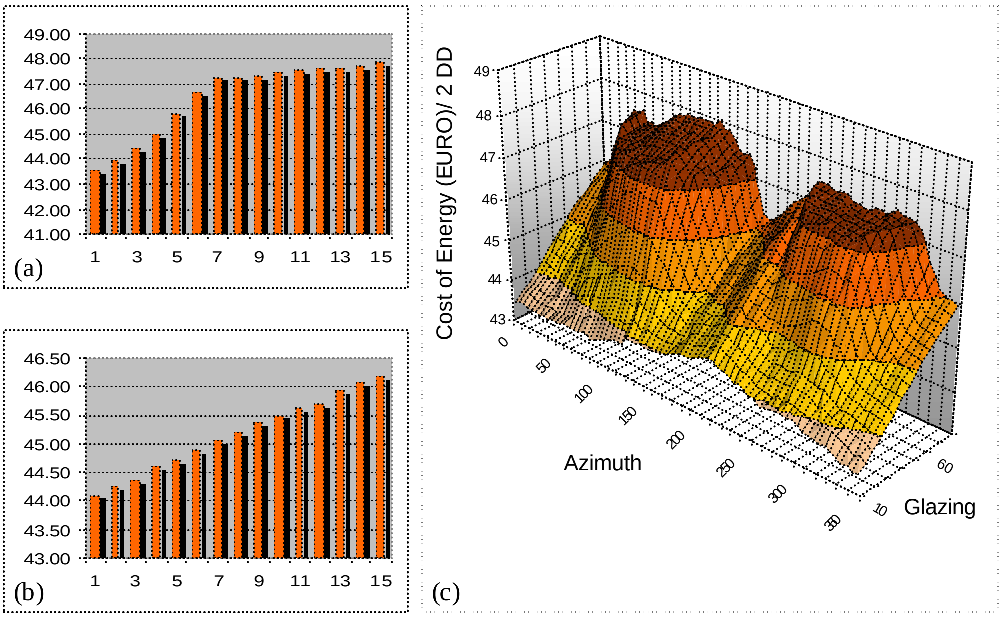

Figure 5: Application of formal optimisation methods to search design space

Optimisation techniques and decision support

Visualization of simulation results through a number of graphs may well reduce the richness of the 'integrated' simulation. Figure 1 explains the complexity in visualizing simulation results from parametric runs of 2 design variables. A 5 zone building has been simulated for 2 design days using ArDOT with EnergyPlus as response generator. Figure 4a shows the relationship between *Glazing Percentage* (10%-90% of the south wall area) and *Cost of Energy* in Euros at *Building Azimuth* of 95deg. Figure 4b shows the same relationship at *Building Azimuth* of 180deg. Two graphs clearly show that 2-D graph based visualization of design variables would be incomprehensible for full spectrum (*Building Azimuth* of 1-360deg), requiring 360 graphs with steps of 1deg. They act on a single view involving two parameters, which is usually not the case, and sometimes mislead the designer. Combining them all to produce surface graphs as in figure 4c may become invalid with more than 3 design parameters.

A large number of design variables influence the environmental design of buildings. To apprehend the interaction of these variables with the building as a system can only be done by searching the optimum values in the design space. Application of formal optimisation methods can offer help in this scenario.

ArDOT

Realizing the constraints and potentials of building simulation programs, a tool has been under development at IRUSE (Informatics Research Unit for Sustainable Engineering), National University of Ireland under the name of ArDOT (**Ar**chitectural **D**esign **O**ptimisation **T**ool).

A lot of emphasis has been placed lately on the use of 'dashboard' type of applications in Operations Research and Business Management. It offers huge potentials for Architectural/ Environmental Design. CAD (Computer Aided Design), being the transformed electronic drawing boards has the potential to be used as 'design dashboard'. User interface research in architectural informatics, has revealed that architects and building designers are comfortable with drawing packages (AutoCAD, Microstation, ArchiCAD) and they intend to kick off analysis, visualization software from within CAD tools. One major impediment in proliferation of digital tools in design is the lack of understanding that translation of data and opening/ reopening another tool to perform a subset of tasks greatly reduces efficiency of the team and the process.

ArDOT has been designed as decision support systems embedded within existing CAD software. For data representation, IFC based shared repository has been implemented. Extraction and archival of data are dealt through API (Application Programming Interface) access to the database. Implementation of a neutral standard greatly enhances interoperability among actors and software. Fundamental concepts of ArDOT is that it connects CAD directly to Building Simulation software and employs optimisation methods to search design space to investigate the complex relationship among conflicting design variables and objectives. User-centric approach has been the focal point of development.

Conclusion

Technology uptake is a complex issue involving a wide variety of factors. Building simulation programs though advanced enough in terms of accuracy and domain representation has failed to address the issues of usability - a determining factor for uptake of technology. The way to accomplish a task differs greatly among design professionals. The use of a generalized simulation tool has failed to cater for the needs of professionals with diversified objectives. Decision support systems harnessing potentials offered by building simulation and optimisation techniques have been proposed as alternatives in this article.

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