Interface Design for Building Performance Modeling: Information Representation and Transformation

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Building design is an integrative endeavor encompassing a multi-variate agenda that deals simultaneously with issues of architectural elements, their attributes (geometry, material properties, etc.), contextual variables (e.g., the uncontrollable external environmental conditions), and building performance variables (e.g., the potentially controllable indoor environment in terms of thermal, acoustical, visual requirements). Ultimately, an important objective of design is to create built environments that are responsive to occupant needs and building performance requirements. This paper will suggest a framework for developing appropriate representations of the complexities involved in building performance simulation. This is based on studies of the communication requirements pertaining to the informational content involved in the design process, and the interfacial relationships between various analytical components as well as between the user and the system. The applicability and effectiveness of this theoretical framework is demonstrated using the example of a fully *operational hygro-thermal analysis program (META-4) developed by the authors.*

Keywords: interface design, building performance, modelling

1 Introduction

An integrative view of the design process implies a multi-variate agenda that deals simultaneously with all the fundamental elements of architecture, namely, the formal attributes (e.g. geometry), semantic information (e.g. physical properties) and contextual variables (e.g. the prevailing external environmental conditions and desirable indoor conditions). Ultimately, these activities should be focused toward creating built environments that are responsive to occupant needs and expectations while demonstrating sensitivity to the socio-economical and ecological interests and concerns at large.

Over the past two decades, researchers have sought principled approaches to developing an integrated computer-aided architectural design environment. Numerous theoretical and philosophical "disputes involved in this ostentatious endeavor (particularly with regard to the definition of design), have yet to be resolved and could conceivably be debated perpetually. However, in the context of building performance driven design activities, research and development has provided a sufficiently rich basis for discussion on a framework for an integrative computer aided design decision support system. For the purpose of this paper, building performance denotes requirements that need to be assiduously met by parties to the building delivery process (viz., energy conservation, ecological impact, thermal, acoustical as well as visual and indoor air quality). Furthermore, these requirements should also be considered concurrently to ensure that design actions to fulfil one set of requirements do not inadvertently create side-effects that impinge upon the fulfilment of another (Hartkopf et al. 1988, Mahdavi & Lam 1991).

The computer would be an indispensable tool to resolve the complexities involved in adopting this concept. Yet, as computer technologies continue to advance at a rapid pace, the chasm between architectural practice and research and development activities seems to have widened further. It has been observed that very few architects today have ever used any computer based performance simulation programmes, and this might even hold true for CAD systems in the future if they remain as production' rather than effective design tools (Milne 1991).

As developers of computer based design support systems, a key issue that has been to addressed is communication. Notwithstanding the increased technological capacity, some fundamental objectives remain. How can we encourage practitioners to use the tools? How can we hold their attention and ensure continuous usage and upgrade? How can we facilitate their understanding and application of the information towards solving a given design problem? How can we help people to acquire and retain knowledge of the concept that is embedded in the development of the tool, which in this case concerns building performance?

2 Communication phases in computational design support systems

It has been suggested that communication within an integrated computational design support system as well as between the system and the user takes place in three different phases that represent the three "faces" of computers: innerface, outerface and interface (Marcus 1983). In terms of building performance simulation, the innerfaces may be regarded as the diverse range of formalized knowledge units (system of rules, procedural algorithms, databases and libraries, generative design modules, etc.) that are typically encountered. The outerfaces are the displays of the results of the simulation processes in the various forms (alpha-numeric and/or graphical). The interfaces are the frames of command/control that users have to negotiate with. This human-computer connection allows the user to understand and manipulate the functional power of the system, serving as a vital channel for effective informational flux between the innerfaces and outerfaces. Without this "handle" on the tool, the program is basically meaningless. All these communicative phases have to be simultaneously considered in the development of an integrated computational environment.

3 Innerface representation for building performance evaluation

In software engineering of performance-based CAD tools, two pertinent aspects of analysis are important, viz., data modeling and activity modeling in the innerface representation (Wasserman et al. 1985).

3.1 Data modeling

In building performance simulation, the information required include the formal, semantic, contextual and performance related information representation relevant to the design (Figure 1). Numerous paradigms have been promulgated to try to capture these representations. For example, it has been generally recognised that conventional CAD sytems are not end-user tools but serve as platforms for the development of domain-specific design applications. As such, efforts have been directed to develop standard product models such as PDES-STEP (Smith 1986), novel data modeling techniques and "intelligent" database schemas to facilitate both the incorporation of existing domain specific knowledge and also the modification and extension of that knowledge for particular design projects (Eastman 1991).

Contextual	weather data (temp., RH, solar radiation, etc.)
Formal	geometric configuration, orientation
Semantic (or Attributive)	dynamic material properties (e.g. moisture related thermal conductivity, moisture distribution mechanism), sound absorption coefficient, etc.
Performance Indices	condensation risks, energy conservation, component integrity, daylight distribution, noise level. etc.

Figure 1. Definition of Contextual, Formal, Semantic, and Performance Variables.

Regardless of which internal data structure or schema is adopted, it is crucial to devise an effective channel to communicate this semantic information explicitly to the user. Almost half a century ago, it has already been observed that *"the architect., is remote from the materials of which his buildings are made; he relies on specialists to convey to him the dry bones of technical information which he is often incapable of assimilating and which fails to give him the feeling of a material which accompanies the close association of a craftsman" (Michaels 1950).* Today, given the increasing range and sophistication of building materials, often orignating from diverse geographical sources, the problem of this alienation is further exacerbated. Nevertheless, architects are still primarily responsible for the specification or materials in design and therefore need to be continuously educated in discerning the pertinent factors and properties so that he is able to compare products according to certain established and acceptable evaluation format. An example of such product information disclosure with respect to one performance evaluation is given in Section 6.2 below. It further highlights the added complexity in that material properties are not necessarily static but will vary according to dynamic changes in the contextual parameters. Hence, it also suggests that the designer should be prompted to consider not only the external "uncontrollable' climatic factors as well as to specify the commonly controllable internal conditions according to the different functional requirements in the design.

3.2 Activity modeling

Activity modeling within an integrated computational environment for performance evaluation requires multiple strategies to handle the complex representations involved. This has been demonstrated through the development of a computer aided simulation tool, META-4 (Mass and Energy Transfer Analysis) to predict and visualize the process of heat transfer, water vapor diffusion and moisture migration through building elements (Mahdavi and Lam 1994). This is part of the ongoing research effort to establish an integrative approach to building enclosure design evaluation.

The development of META-4 can be regarded as one of the classes of diverse decision support systems (DDS's), which integrate many common processes, including data management, numerical computation, geometric procedures, rule-based systems, graphical representation, and heuristics. It is conceived as a "front-end" building design support and educational tool, and is to be regarded as a prototype module within a broader computer aided integrative building performance simulation environment. The selection of the computational platform for this development is intended to:

(a) encourage the pervasive use of such DDS's at the personal computer level.

(b) capitalize on the graphic user interface capabilities and potentials in the selected computing environment to provide an intuitive user-interface for efficient manmachine interaction.

Many models have been developed in the past to simulate the combined mass and energy transfer phenomenon, which include both steady state as well as transient methods. However, the majority of these methods adopt primarily a quantitative assessment approach. The primary intention of the META-4 model is to develop an interactive educational and design tool for rapid and graphically supported dynamic analysis of the hygro-thermal behavior of building components, identification of condensation risk and generation of alternative component configurations.

The detailed mechanics of the META-4 simulation engine is beyond the scope of this paper but interested readers may refer to Mahdavi and Lam (1993, 1994). Of interest here is the conceptualisation and design of the user interface for the program.

4 User and task oriented system interface

Jones (1989) defines a user interface as any aspect of a system that shows through to the user and forms part of the users conceptual model of the system. It enables the user to communicate with the system in such a way that the behaviour of the system becomes
predictable and the functionality becomes apparent. Many design guides are offered in the literature to realise this ideal mode of man-machine interaction. To further extend the purpose of this interaction, it has been suggested that 'the (software) designer, instead of simply making an object or thing, is actually creating a persuasive argument that comes to life whenever a user considers or uses a product as a means to some end" (Buchanan 1989). This is an important factor for consideration if we are to capture the sustained interest and imagination of architects in the use of CAD tools.

The motivations to provide effective design support tools are well acknowledged. However, in reality, much of these efforts and applications have only found a limited audience in the architectural design profession. Several reasons may be suggested. Firstly, the conceptual development might have been based on a set of assumptions which may or may not adequately reflect the need and expectation of the designer. Secondly, in the pursuit of technical rigor and competency (which is essential and commendable), the resulting tools often become overtly complex for use by many designers.

In an attempt to provide ease of use, many early "traditional" design support software opted for simplified input/output interfaces while encapsulating the functional modules within a "black box". This approach tended to generate results that are limiting in terms of design evaluation. In the other extreme, completely open and "generic" computational frameworks have been introduced whereby the functions can be represented as "building blocks" that can be actively defined and manipulated by the user according to the task requirements. Both approaches have their respective advantages and shortcomings. The key point in developing design tools is to acknowledge that there is a wide spectrum of the level of skill and experience between the novice and the expert user. It is also important to recognize that an individual's skill level is progressively changing with time as he becomes familiar with the inherent concepts and routines of the program.

In practice, there are definable stages within the architectural design process, generally referred to as preliminary (or sketch) design and detailed design. The comprehensiveness of information requirements and complexity of tasks involved are clearly different in each phase. These factors evidently imply the need for a system interface design concept that supports "on-line" adaptability in handling and processing information according to the prevailing needs.

5 Information representation and transformation

One of the predominant factors which has contributed to the increasingly pervasive impact of computers is the emergence of the so-called "user-friendly" graphic user interface. Such interfaces are now generally regarded almost as "standard" for most major PC computer platforms. The formal realization of the graphic user interface revolves around the fundamental concept of metaphors in the general sense and implemented specifically as icons and menus in operating systems. This has decisively replaced the traditional Command Line Input interface which was the first generation of userinteractive interface made available. There are examples of user interface paradigms that utilize a graphic toolbox with metaphorical representations to provide recognizable, consistent, repeatable and understandable operations. These characteristics are desirable as the sense of familiarity enables users to learn the primary functions of the a family of software applications efficiently and furthermore encouraging them to proceed to explore the more complex operations as the level of interest and/or knowledge increases. However, such features do not necessarily address the issue of informational representation and transformation pertaining to the design tasks that are of interest. The potential for developing truly beneficial tools to support creative design requires much more than simplistic iconic (or reductionistic) representation of reality. It is argued that the tools and capabilities of the future should support and teach by associating themselves to the users experience and affect by relating to his or her developing context. The development of such tools with the appropriate "relational interfaces" could conceivably begin to address the real world (in terms of the given physical constraints) and, perhaps, more importantly in giving due consideration to the human user of the system (Romeu 1991).

Within any graphic user interface environment, data can be communicated through digital and/or analog means. Traditional digital interfaces can subtly affect the way we relate to reality. While it can provide precision and accuracy, the numerical output is often devoid of context and therefore lacks the capability of conveying a relative understanding of the impact of dynamic input parameters on the results of the computational process. Particularly in building performance simulation, the latter feature is often more critical than aspiring to achieve a high degree of digital accuracy. The conveyance of the "pattern" of response in a given context in relation to the transient environmental factors can be more educational and effective for design decision support in that the user is able to gain a better appreciation of the "boundary conditions" in which the design can be realized integratively with other performance requirements. Such a function would necessitate the implementation of an informational transformation mechanism in order to communicate the data in an effective and persuasive manner.

Enhanced capabilities for simulation and visualization has the ability to radically change the static "statement" into an interactive "dialog'. No doubt traditional interface design has filled a need but new directions are now required to provide a "real time dialog" between the system and the user. The system has to assume roles as 'communicators" within a more demanding scientific and linguistic context. To illustrate the application of this conceptual approach, the development of the META-4 user interface is discussed below.

6 User interface design for meta-4

In the development of the META-4 computational environment, an effective graphic interface for structuring data input and visualization of the hygro-thermal process is provided. Building performance simulation requires substantial input data in terms of material properties and configuration, dynamic external environmental conditions and the desired internal environmental conditions to satisfy functional requirements and comfort criteria. In META-4, a comprehensive "single-screen" graphic input format has been developed for both the steady-state and the transient simulation modes. It allows the user to immediately gain an overview of the design parameters and data input requirements which is supported by relevant built-in libraries and default values for each variable. Inherent in this approach is the assurance of data acceptability (type matching) and dimensional accuracy. The graphic interface is designed to efficiently facilitate the management and processing of data relevant to the application.

6.1 Boundary condition window

Upon selection of the simulation mode from the Simulation Model window (Figure 2), the single screen input comprise of three separate windows, namely, a Construction Element Editor, Construction Graphics, and the Boundary Condition. Depending on the simulation model selected, the relevant Boundary Condition window will be displayed to prompt the user for the correct definition (Figure 3, Figure 4 and Figure 5). The difference between Transient Simulation Mode 1 and Mode 2 lies in specification of the internal boundary condition, whereby in the first case, seasonal block temperature and relative humidity can be specified. After the weather file is selected for the transient mode, the user can review the geographical information related to that city (i.e., latitude, longitude, time meridian [degrees] and height above sea-level [ml).

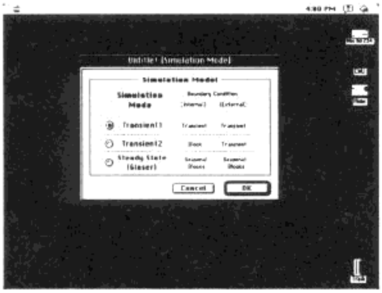

Figure 2. Simulation mode selection window.

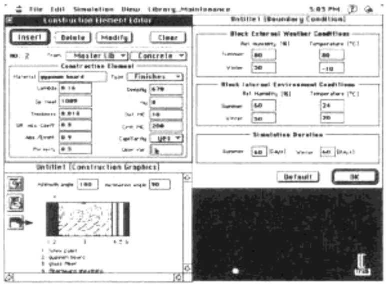

Figure 3. Single-screen data input format for the steady-state (Glaser) simulation mode.

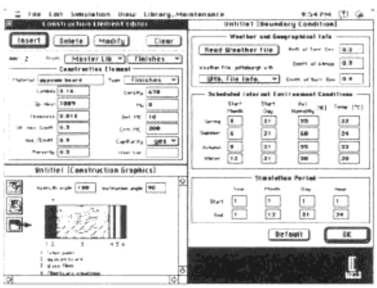

Figure 4. Single-screen data input format for the transient simulation mode #1 with weather data file and schedule selection.

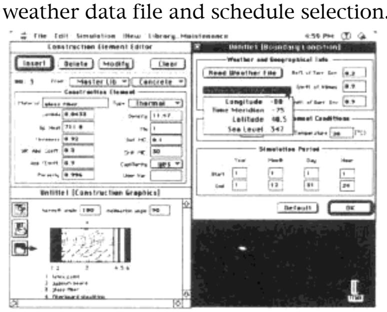

Figure 5. Single-screen data input format for the transient simulation mode #2 with weather data file and schedule selection and providing geographical information of the city when weather file is loaded.

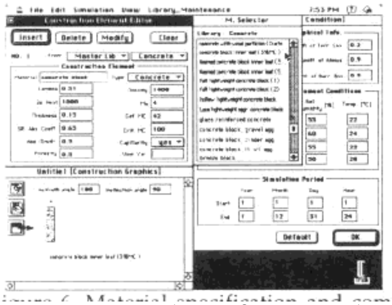

Figure 6. Material specification and component configuration supported by a library of materials and a graphical interface for visualization and manipulation.

6.2 *Construction graphics and construction element editor windows*

Material specification and the configuration of any multi-layered building enclosure component is supported by a built-in META-4 Master Material Library (Figure 6). In the building industry, new materials are continuously being introduced. Therefore, it is necessary for the library of materials to be customizable and upgradable. However, maintenance of the Master Library is restricted only to authorized personnel to avoid any accidental corruption of the file. Besides the Master Material Library, users can create their own individual user library which can be freely customized using the Library Editor (Figure 7).

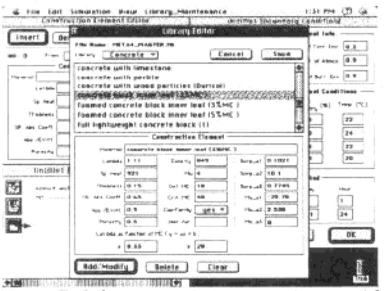

Figure 7. Library maintenance is provided online both for the Master Library (reserved for authorized users only) and the User Library.

It is important to note that not all material properties are 'static' in nature. For example the thermal conductivity value is a function of the prevailing moisture content of the material at a certain state of simulation process which may be representation by a mathematical function or graphicall as shown in Figure 8 (Gösele and Schüle 1983). Similarly, the relationship between moisture content and relative humidity at equilibrium at a constant temperature (Figure 9), is depicted by the sorption isotherm of a mateial Hansen (1989), which may be represented graphically. Such detailed information representation is accessible by the experienced user.

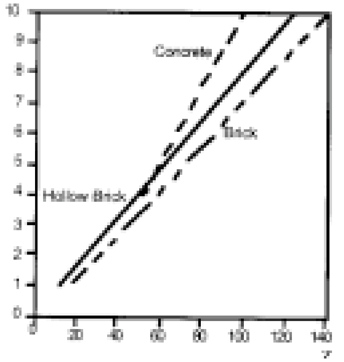

Figure 8. Relationship between the thermal resistance incremental factor (Z) and moisture content (uv).

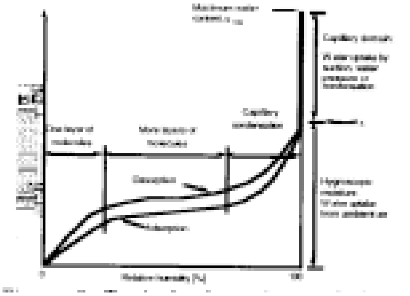

Figure 9. Typical adsorption and desorption isotherm curves which show connected values of relative humidity of the ambient air and water content of the material at equilibrium at a constant temperature (cp. Hansen 1989)

The Construction Element Editor Window is dynamically linked to both the Library window and the Construction Graphics window. When a material is selected from the Library, its properties are immediately shown in the Construction Element Editor window. Modification to the values can be made before accepting it. The material can then be inserted into the component configuration at any position to the right side of any previously inserted elements by clicking in that element in the Construction Graphics window. Clicking outside of all the elements would automatically cause the new material to be inserted as the first internal element of the construction. Similarly, by clicking in any existing element, the properties will appear on the Element Editor window for further manipulation. It can be copied and inserted into another position, or deleted from the construction. The component configuration can be saved on file for future retrieval (Figure 10). This graphically oriented interactive mode for designing an enclosure component proves to be a very efficient method particularly to support rapid generation of alternative configurations.

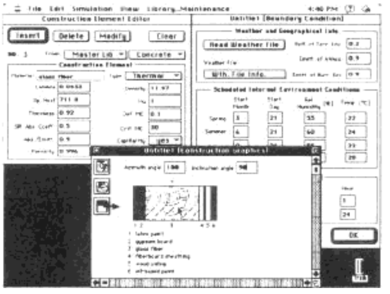

Figure 10. Retrieval of existing construction files is facilitated.

6.3 Simulation process preferences and control

Considerable flexibility in user preference and control of the simulation process is offered through the interface design. Prior to starting the simulation, the user can elect to save the hygro-thermal analysis results, the complete solar radiation results generated by SOL-ARIS (which will include all values of direct, diffuse, and global irradiance as well as solar azimuth and altitude on an hourly basis) and the average hourly solar irradiance values of each month for the entire simulation duration (Figure 11). For each input variable, an acceptable range of values is predefined and used as the basis for data entry type checking. However, the "experienced" user may occasionally wish to explore the consequences of specifying certain parameters beyond the normal recommended ranges. This can simply be achieved by deselecting the data type checking function. All transient simulations by default include the effects of solar radiation in the specification of the external boundary conditions. There is an option to omit this effect in the transient mode by deselecting the solar computation procedure. Preference for viewing of the result of the simulation is also offered and this function is described below.

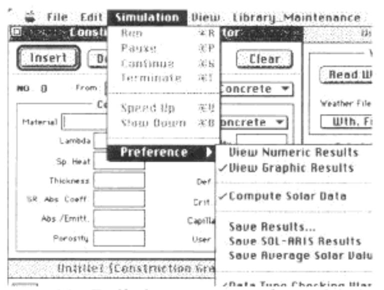

Figure 11. Pull-down menu for selecting simulation preferences and control options.

Another significant feature is the ability to vary the time step of the transient simulation process, either at the beginning or "on-the-fly' during the simulation process. This functionality may be necessarily for certain components which comprise materials that are sensitive to moisture fluctuations, particularly when the discretized sublayers are small.

6.4 Result output representation

The result output interface tracks the "real-time" simulation process and presents the results numerically and/or graphically to the user. The benefit of the graphic output is to enable the user to observe critical conditions that may arise during the simulation period. The graphical representation of temperature, water vapor and moisture distribution within the enclosure component sub-layers provides an effective representation of the pattern of behavior of the component as the boundary conditions vary in time (Figure 12). 1 he ability to conduct parametric simulation studies and observe the response patterns graphically promises to be particularly effective from the pedagogical point of view.

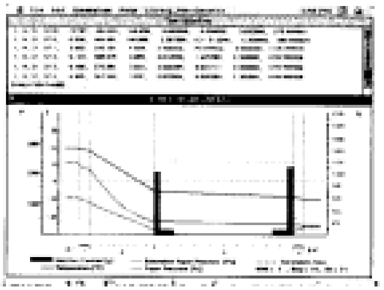

Figure 12. Example of a numeric and graphic output window illustrating saturation and vapor pressure curves, temperature distribution as well as moisture content in each component sublayer. Nodes that are saturated are indicated with a red dot.

Opting to view the numerical and/or graphical output will inevitably slow down the simulation process. Yet it is important for the user to periodically track the progress to see if the hygro-thermal performance of the component is still acceptable at certain time step. Therefore, a function is incorporated to allow the user to toggle any of text and graphic display on or off during runtime. The process can also be intentionally slowed down so as to offer a longer time for viewing the graphical display of the results. The necessary functions to pause, continue and terminate the simulation is also provided. When the program is paused, the user can return to the computer system's desktop finder to activate a screen capture program to obtain a snapshot of the graphical plot of the simulation result. It is also feasible to utilize the multi-finder capabilities to allow the simulation to proceed in the background while the user works with another program.

To save the results on file, the frequency of data recording has to be stipulated either on a daily or monthly basis. A very important feature provided by META-4 is the capability of retrieving a result file generated from a previous simulation session and reviewing it numerically or graphically in quick time (Figure 13). The usual control functions for this information display is provided.

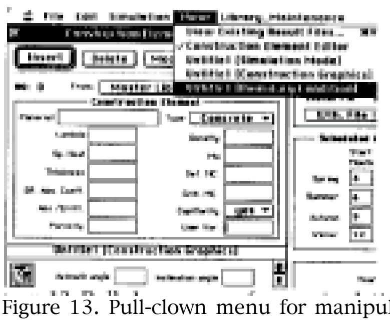

Figure 13. Pull-clown menu for manipulating associated windows of a simulation model. The retrieval and viewing of existing result files is also provided.

7 Concluding remarks

This paper has provided a detailed description of an approach taken in user interface design for one aspect of building performance evaluation of building enclosure design. It attempts to capture the pertinent interface design principles which will hopefully encourage a more pervasive use of such evaluation tools particularly in the early design stage. It is also intended to serve as an educational tool, in the belief that while the knowledge of scientific and technological development is far beyond the mastery of any one individual, the architect must still aim at knowing sufficient of the principles of each specialised subject on which his design depends to enable him to lead and not to follow, to demand and not to acquiesce.

Despite the provision of an interactive graphic user interface support, the fundamental mode of communication between the user and the computer is still predominantly "mono-directional. The simulation procedure is based on the transformation of pertinent design data (e.g., geometry, materials, environmental conditions) into a set of performance indicators. The tool does not "directly" provide information on possible design configurations that would meet desired performance specification, but instead requires a computationally unsupported convergence toward a solution through extensive parametric studies. There is need for simulation environments that facilitate not only the evaluation of a given design solution in terms of its performance but also the potential derivation of formal and "behavioral" implications of performance criteria. research in this aspect toward the development of "two-way" (bi-directional) inference approach as well as a more generic "open' simulation environments have been reported (Mahdavi & Berberidou 1993, 1994, Mahdavi 1993). This will undoubtedly call for a critical reassessment of the user interface design principles to meet the emerging challenge for developing effective performance-based design decision support systems in architecture.

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