THE PLACE OF COMPUTER GRAPHICS IN BUILDING ENERGY SIMULATION

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- Abstract

Architects, engineers, building managers, and others who are concerned about designing and managing energy-efficient buildings could benefit from the use of energy simulation packages but do not often take advantage of them. The numeric input and output required for most energy simulation packages makes them difficult to use. Ideally one would like to create a model of the building to be simulated using interactive graphics and to display the results of a simulation graphically. This paper describes a prototype **system for generating the input necessary to perform** a building energy analysis and for interpreting the output from such an analysis using interactive computer graphics tools.

INTRODUCTION

As more people involved with the design, construction, and management of buildings use computers, more data describing those buildings exists in digital form. Information describing the building geometry, attributes of materials, operating conditions, climate conditions, and site conditions may exist as data stored in a computer along with other kinds of data related to the building project. Often the information is stored in different computer systems and in formats which are incompatible with each other. To make optimum use of such information, it is necessary to organize the data into an integrated model of the building (Fig. 1). In such a model pieces of information are related to and dependent on each other. Various "views" of the database allow people with specific concerns in the building design, management, and construction process to store, retrieve and manipulate the model of the building.

One possible set of views of the building model is concerned with the evaluation of a building's energy performance. As integrated building model databases are developed, it will be useful to extract the information necessary to perform an energy simulation from the database, format that information for an analysis package, perform the analysis, capture the results of the analysis, and incorporate those results in the model. To do this, it is necessary to have a model that can contain all of the information necessary to perform the analysis. In addition, three requirements must be met: tools to input and manipulate that information must be available, the capability to store analysis results and extract those results in a meaningful form must be available, and a mechanism to extract data from the model and format it for input to the analysis package must be available.

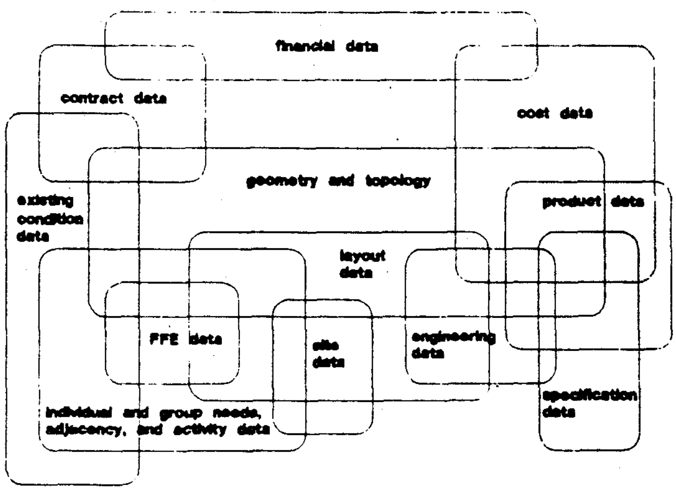

Figure 1 - An integrated building model

It is conceivable that analysis packages could be developed that work directly from data stored in the building model, but to date energy simulation packages have been developed independently of building model databases. Several good analysis packages are available but none is related to a building model database. To take advantage of these packages, they would need modifications to include the three components of a successful system that are outlined above.

In 1982, at the Program of Computer Graphics at Cornell University, we developed a prototype system for the storage and manipulation of information related to energy analysis. This system was called the *ENERGY design environment* and was intended to be a computer graphics tool that allowed architects to easily manipulate building descriptions that contained the data necessary for building energy simulation. It was hoped that such a system would make it easier for architects to use building energy simulation tools as an integral part of the design process thus resulting in more energy-efficient buildings. Much of the following text is an excerpt from (1) which describes this work in more detail.

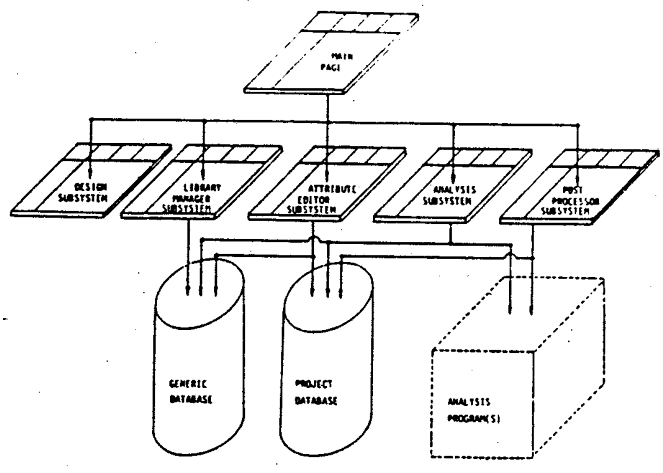

Figure 2 - Components of the ENERGY design environment

THE ENERGY DESIGN ENVIRONMENT

The ENERGY design environment is designed to be a highly interactive, visual means for architects to easily create and manipulate large complex building descriptions. It consists of graphic input tools which allow the architect to create a volumetric description of the building geometry; to create libraries of material, wall section, operating schedule, and window data, and to assign specific elements of these libraries to geometric entities in the building description. This information is stored in a database that relates geometric data, attribute data, and thermal performance data for a particular design problem.

The design environment also provides output tools that the architect may use to graphically study the thermal performance of a building and its components. These include two and three-dimensional graphs of thermal performance, color-coded representations of heat loss and gain, and tools that allow the architect to study the relationship of solar orientation to shading patterns using shadow algorithms. These tools are structured to permit the architect to interactively view the relationships between various components and their effect on the building's energy performance.

Overview. The ENERGY design environment acts as an interface between the architect and energy analysis tools. It allows the architect to deal with the energy implications of a design problem using a familiar graphic vocabulary. It manages information on building geometry, thermal performance, orientation, weather data, and scheduling data, all of which is necessary to perform a building energy analysis. Included in the ENERGY design environment are aids to design decision making, a preprocessor for energy analysis data, and a postprocessor and display system for the results of an energy analysis. Visual cues are used whenever possible to facilitate interaction with the computer. Rather than forcing the architect to conform to the computer (or programmer's) mode of working, the ENERGY system has been designed to conform to the architect's mode of working.

Structure of the system. The ENERGY design environment consists of four components: the ENERGY program, the project database, the generic database, and one or more analysis programs (Fig. 2). The primary component is the ENERGY program which coordinates the activities of other components and forms the interface between the architect and the computer. The architect communicates with the ENERGY program via menus using graphic input techniques. The menu pages are organized into a hierarchical tree structure containing five major subsystems: design tools to help the architect with design decisions, a library manager to deal with the generic database, an attribute editor to assign project attributes in the project database, a preprocessor to prepare data for analysis and to control execution of the analysis, and a postprocessor to interpret the results of the analysis (Fig. 3). In addition, a view page is provided to allow the architect to display and manipulate images of the building geometry.

Database. Information about each project is contained in a project data file. This file contains all of the information specific to the project and describes the building in sufficient detail for the ENERGY environment to perform the tasks required of it.

Each project file contains a complete description of project-specific data including:

- building geometry
- building location and orientation
- project name
- analysis results
- historical record of work done on the project

In addition, the project file contains pointers to the generic database. These pointers do not directly reference elements in the generic data libraries but reference a map in the project file, which in turn points to specific generic data elements. This method of indirect referencing allows the designer to change the reference to an entire class of elements without changing each instance of the pointer.

The project file is structured as a tree and is implemented using a hierarchical polygonal database. This database allows the grouping of geometric entities and the assignment of attributes to these groups.

DESIGN TOOLS

In many cases, the architect does not need to perform a complete energy analysis to determine the energy implications of a design decision. During the design process, it is often more useful for the architect to get a rough idea of thermal performance using quick, approximate methods. For this reason, the ENERGY environment provides tools that allow the architect to evaluate a design interactively without the time and expense involved in completing a full thermal analysis of the building. The design tools provided by the ENERGY environment include solar path diagrams and shadowing algorithms.

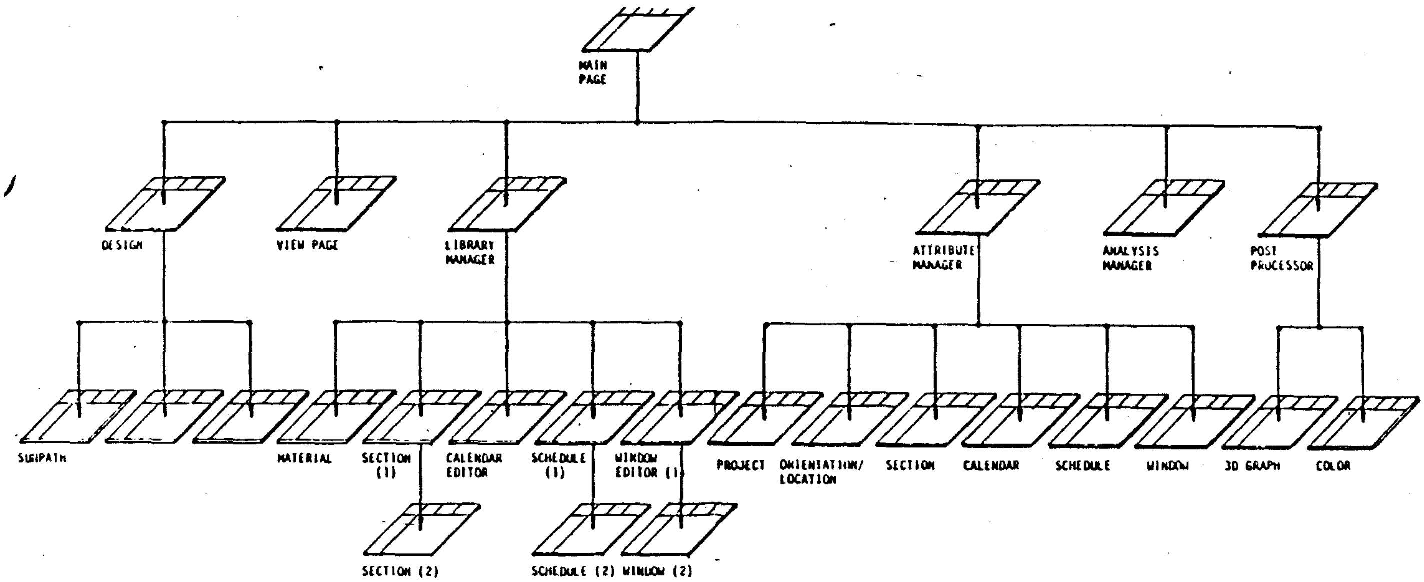

Figure 3 - The menu tree of the ENERGY design environment

Solar path diagrams. Solar path diagrams provide the architect with the means to quickly observe the implications of building form and orientation on solar load. A solar path diagram shows the arc of the sun's position relative to the building for a given latitude, longitude, and date allowing the architect to view the form and orientation of the building at the conceptual design phase and to visually determine its performance due to solar loads. Design alternatives can be quickly evaluated in terms of solar performance.

Shadowing Algorithms. Through the use of the shadowing facility, the architect can display the shadow patterns cast by the building (or group of buildings) at a particular location and time. The shadowing facility uses well known shadowing algorithms to generate this display. As with the sun-path diagrams the shadowed image of the building can aid the architect by providing a quick, visual evaluation of solar load and the shading effects of various building forms and architectural elements.

The design tools provided by the ENERGY environment supplement, rather than replace, a complete thermal load analysis. However, they do allow the architect to repeatedly evaluate a project through a design cycle with a minimum amount of effort.

LIBRARY MANAGER

To perform an accurate and comprehensive building energy analysis, it is necessary to describe geometric data, thermal performance data, and operating conditions in the building. Some of this data is specific to a given building, other data however, is generic. The ENERGY design environment maintains this generic data in a set of libraries. The libraries are maintained by the library manager, which consists of a set of graphic library editors, a set of library access routines, and a set of direct access disk files that contain the library data. Each type of generic data is contained in a separate library and managed by its own editor and access routines.

ATTRIBUTE ASSIGNMENT

The project file described under "database" contains a representation of the building geometry and other project-specific data. The building geometry representation is generated by a geometric modeling program external to the ENERGY environment. To make the project file useful to the ENERGY environment, a large amount of additional information must be stored in the project database. The architect may store and manipulate this information by using the attribute assignment subsystem of the ENERGY environment. This subsystem consists of a set of editors that the architect uses to associate project-specific information and generic data with the appropriate group in the project database.

The attribute assignment subsystem consists of six attribute editors:

- the project attribute editor
- the orientation and location editor
- the section attribute editor
- the calendar attribute editor
- the schedule attribute editor
- the window attribute editor

Each editor allows the architect to graphically assign attribute information to the appropriate group in the project database.

ANALYSIS

To perform an energy analysis of a building, it is necessary to preprocess the data in the project database and execute an analysis program. After the analysis is complete, it is necessary to interpret the results and store them in the project database for future use. The analysis subsystem of the ENERGY environment performs these three functions. It allows the architect to specify interactively which analysis package should be used, to prepare input to the analysis, to control the execution of the analysis. The analysis subsystem automatically interprets the results of the analysis.

Many types of analysis packages could potentially be used with the ENERGY environment. Packages exist to deal with such issues as thermal loads, mechanical system simulation, solar energy concerns, and costs of energy use. The ENERGY design environment is concerned only with thermal load determination analysis. This type of analysis calculates the thermal loads imposed on the building and determines the amount of energy necessary to maintain a specified temperature in the building. These thermal loads are imposed by weather patterns, solar impact, and heat generated by the occupants, lighting, and equipment in the building. The thermal loads calculated by the analysis are used to determine mechanical equipment requirements and operating costs for the building. Although the ENERGY environment deals only with thermal loads, it has the capability to deal with other types of energy analyses.

POSTPROCESSING

After an analysis has been performed, it is necessary to display the analysis results in a form that is meaningful to the architect. The postprocessor subsystem of the ENERGY program performs this function. Analysis results are displayed in graphic form facilitating comparisons between the thermal performance of various building components.

Two means of graphically displaying analysis results in the ENERGY design environment are 3-dimensional graphing of results and color representation.

3D graphing. It is frequently valuable to observe the thermal behavior of a building or its components over time. The 3D graphing facility allows the architect to select a building component at any level of the building group structure and display the analysis results (or a summary of results) associated with it. This package displays the average heat loss/gain for each hour of an average day for each month of the year. The graph may be rotated or scaled to exaggerate or minimize the variation in the heat loss/gain display.

Color representation. Color representation of thermal loads is another means of displaying the results of thermal analysis data. Each building element is given a color code based on its thermal performance. The color coding indicating thermal performance results in a pseudo-color for each polygon in the display of the building. Since the pseudo-color may result in a loss of three-dimensional perception of the building geometry, two displays are generated, one to indicate diffuse shading of the building and another to represent thermal performance parameters. These displays may be viewed on a color raster display device. This capability allows the architect to observe heat flow patterns and to identify at a glance those building components with high levels of heat flow.

The postprocessor allows architects to deal effectively with the results of energy analysis. It allows them to evaluate these results using the visual vocabulary of the designer. It also provides a convenient, graphic means of relating thermal performance to building geometry. The primary goal of the ENERGY environment is to provide a set of tools for the architect to deal with thermal performance of buildings. The postprocessor subsystem meets this goal by providing the architect with the means of clearly and conveniently evaluating the results of an energy analysis.

CONCLUSION

The ENERGY design environment was developed as a prototype design tool that matched the needs of the design process. It was an attempt to make sophisticated energy analysis tools available to architects with limited technical knowledge and expertise in energy analysis.

The next step is to create a general building model that has many of the tools for inputting and manipulating information that were incorporated in the ENERGY system. Energy simulation data could then be extracted from this building model and the results stored in the model.

As architects develop the capabilities of their computer-aided design systems, the need for such a model will increase. In addition, increasing emphasis on building operating efficiency will necessitate integrated building models and software tools to monitor building performance.

The ENERGY design environment illustrates many of the concepts necessary for such an integrated system. It points the way toward a partnership between architect and computer to extend the architect's capabilities to deal with increasingly complex design problems.

REFERENCES

(1) Pittman, Jon H. and Greenberg, Donald P. "An Interactive Graphics Environment for Building Energy Simulation." Computer Graphics Vol. 16, Number 3, August 1982, Pg. 233-241. (Association for Computing Machinery).

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