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Building Design Advisor: Automated integration of multiple simulation tools

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Abstract

The Building Design Advisor (BDA) is a software environment that supports the integrated use of multiple analysis and visualization tools throughout the building design process, from the initial, conceptual and schematic phases to the detailed specification of building components and systems. Based on a comprehensive design theory, the BDA uses an object-oriented representation of the building and its context, and acts as a data manager and process controller to allow building designers to benefit from the capabilities of multiple tools.

The BDA provides a graphical user interface that consists of two main elements: the Building Browser and the Decision Desktop. The Browser allows building designers to quickly navigate through the multitude of descriptive and performance parameters addressed by the analysis and visualization tools linked to the BDA. Through the Browser the user can edit the values of input parameters and select any number of input and/or output parameters for display in the Decision Desktop. The Desktop allows building designers to compare multiple design alternatives with respect to multiple descriptive and performance parameters addressed by the tools linked to the BDA.

The BDA is implemented as a Windows®-based application for personal computers. Its initial version is linked to a Schematic Graphic Editor (SGE), which allows designers to quickly and easily specify the geometric characteristics of building components and systems. For every object created in the SGE, the BDA activates a Default Value Selector (DVS) mechanism that selects “smart” default values from a Prototypes Database for all non-geometric parameters required as input to the analysis and visualization tools linked to the BDA. In addition to the SGE that is an integral part of its user interface, the initial version of the BDA is linked to a daylight analysis tool, an energy analysis tool, and a multimedia, Web-based Case Studies Database (CSD). The next version of the BDA will be linked to additional analysis tools, such as the DOE-2 (thermal, energy and energy cost) and RADIANCE (day/lighting and rendering) computer programs. Plans for the future include the development of links to cost estimating and environmental impact modules, building rating systems, CAD software and electronic product catalogs.

Introduction

The continuously decreasing cost of computing power has resulted in very powerful, yet affordable computer systems. Several building analysis and visualization programs that were originally developed and maintained on mainframe systems are now available on workstation and personal computers. Such programs include the DOE-2 building energy simulation program [Birdsall et al. 1990, Winkelmann et al. 1993], the SUPERLITE daylighting program [Modest 1982], the RADIANCE lighting and rendering program [Ward 1990], and the COMIS air flow and indoor air quality program [Feustel 1992]. Referred to as “simulation tools,” these programs use sophisticated algorithms that model the physical behavior of buildings under varying environmental conditions. When used during the building design process to predict the performance of various design alternatives with respect to considerations such as comfort, energy, cost, esthetics, etc., these programs can greatly contribute toward informed, wiser decisions. This, in turn, should translate into the design and construction of better buildings.

A major drawback of existing building simulation tools is that they were not designed for use by building designers. Rather, they were designed for use by research scientists, such as those who originally developed them. As a result, they lack an easy and friendly mechanism for entering input data and reviewing output. Their use typically requires a steep and prolonged learning curve. Even after such a significant investment, each subsequent use of such simulation programs requires time-consuming preparation of “input files” (i.e., descriptions of buildings and their surroundings in terms of numbers and character strings that follow a specific syntax). Moreover, the produced “output files” are typically in the form of alphanumeric tables, which are difficult to review and interpret. As a result, despite their relative usefulness and widespread availability, these simulation tools are rarely used by the building design community.

The Building Design Advisor (BDA) is a computer program designed to make the use of simulation tools quick and easy. It allows the use of sophisticated simulation tools from the early, schematic phases of building design to the detailed specification of building components and systems. The BDA is designed to allow for the transparent, integrated, and concurrent use of multiple simulation tools and databases, through a single graphical user-interface that supports multi-criterion decision-making.

Background

The BDA research and development efforts were initiated in the mid-1980s. The objective at that time was to explore how computers could be used to promote the consideration of energy-efficient strategies (e.g., daylighting) and technologies (e.g., heat pumps) during the building design process. Soon enough, it became apparent that *general* statements about the performance of strategies and technologies (e.g., *on the average*, daylighting can save 50% of electric energy) were not enough for decision-making in *specific* design projects. Building designers need to know the *specific* energy performance of strategies and technologies under the *particular* context of the problem at hand. Moreover, they need to know the non-energy performance as well, that is comfort, cost, esthetics, etc. Several approaches to this problem were considered at that time, many of which focused on the use of artificial intelligence techniques to automate the use of multiple simulation tools and address the needs of the decision-making process. These efforts, combined with ongoing research in design theories and methods, resulted in the formulation of a comprehensive design theory which clearly distinguishes between tasks that *can* and *cannot* be delegated to computers [Papamichael and Protzen 1993].

After various incarnations of a demonstration prototype, the actual BDA development efforts were initiated in July 1994. These efforts focused on the design and development of

- the BDA core algorithms for the overall control of processes and data management,
- an integrated data model for the representation of the building and its context,
- a programming interface for the development of links to external simulation tools, and
- a graphical user interface for easy editing and navigation though data and processes.

The BDA core program

Although the BDA appears to the user as a single application, it is in fact several applications which work together to form an integrated environment where design alternatives can be developed, compared, and analyzed in different domain areas, such as daylighting, energy, cost, etc. (Figure 1). Each application within the BDA environment provides a specific service. Some applications may remain active through an entire user session, while others are invoked periodically to perform specific tasks, after which they are terminated. This approach provides a flexible software architecture in which additional applications can be developed when greater functionality is required. By dividing functionality into small applications, we avoid delivering a single large application, which must be loaded in its entirety regardless of the needs of the user.

The core program is the main BDA module from which other applications are launched. It remains active through an entire user session and provides the required data management and process control through a graphical user-interface. The core BDA program maintains a rich object-oriented model of the entire building and its context. This model includes both geometric and non-geometric descriptions of the building, its components and systems, as well as performance measures addressed by the attached simulation tools. Through its graphical user-interface, the core program allows users to

- easily navigate through the object-oriented model of the building,
- request computations by the simulation tools linked to the BDA,
- perform queries to the attached databases, and
- review results from computations and data queries in a variety of graphical displays.

Based on user requests, the core program controls the preparation and submission of the input to the appropriate tools and databases, and the merging of their output into the integrated data model for potential review and subsequent use by other tools.

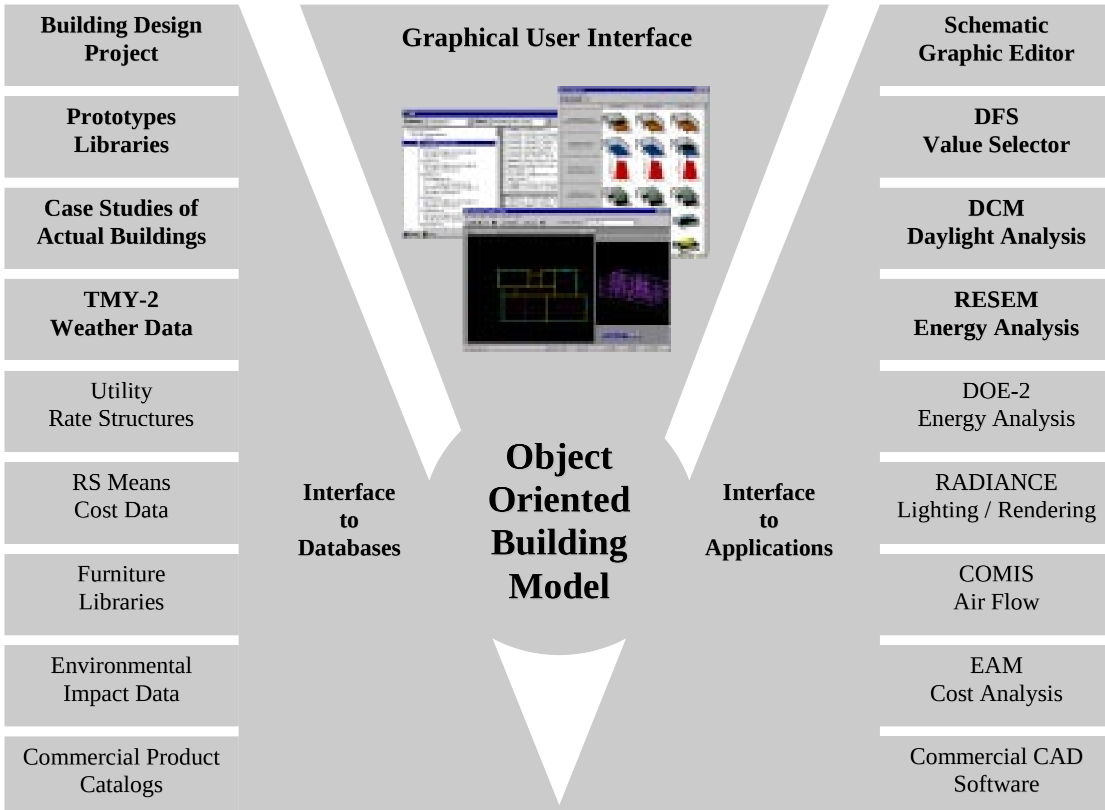


Figure 1. *A schematic diagram showing the Building Design Advisor software environment.* **Bold face text** *indicates databases and applications that are part of the 1.0 release. The rest of the modules will be linked in future BDA versions.*

The integrated data model

Depending on the performance aspects being addressed (e.g., energy, esthetics, cost, etc.) simulation tools use different building modeling representations. A thermal simulation program, such as DOE-2, uses a building description in terms of thermal barriers with properties such as U-value, solar transmittance, etc., required for heat transfer computations. A lighting and rendering simulation program, such as RADIANCE, uses a building description in terms of geometric solids, such as cones, spheres, etc., with properties such as texture, visible reflectance, etc., required for illuminance and luminance computations. Even if simulation programs such as DOE-2 and RADIANCE were easy to use, building designers would have to describe each alternative design multiple times, in terms of thermal barriers, geometric solids, etc. To address this problem, the BDA uses a single, object-oriented building representation, which allows building designers to describe the building in terms of real world objects such as spaces, walls, windows, etc. The BDA then automatically “translates” these objects into thermal barriers, geometric solids, etc., as required by the simulation tools linked to the BDA, thus relieving building designers from the modeling complexities associated with each simulation tool.

The BDA uses a *generic* object-oriented representation of the building. It is *generic* in that it is not focused towards any specific domain or application, but instead models the actual physical components of the building. An object-oriented representation is based on the notion of *objects* (e.g., windows) that have *parameters* (e.g., U-value, visible transmittance), *relations* (e.g., composed of) to other *objects* (e.g., frame, glazing), and *methods* (e.g., display) which describe their behavior. The advantage of an object-oriented approach is that each object has not only a description of itself, but also an explicit behavior built into it which enables it to manage its own actions. In BDA, for example, a Wall object contains a Construction object (which defines its materials), and two Surface objects (one for each side) describing the characteristics of the final finish (Figure 2). If the room on one side of an interior wall is deleted, the Wall object can automatically change its Construction and exterior Surface objects to match the requirements for an exterior wall. This kind of interaction is possible because each object in the BDA system has knowledge about itself and its actions.

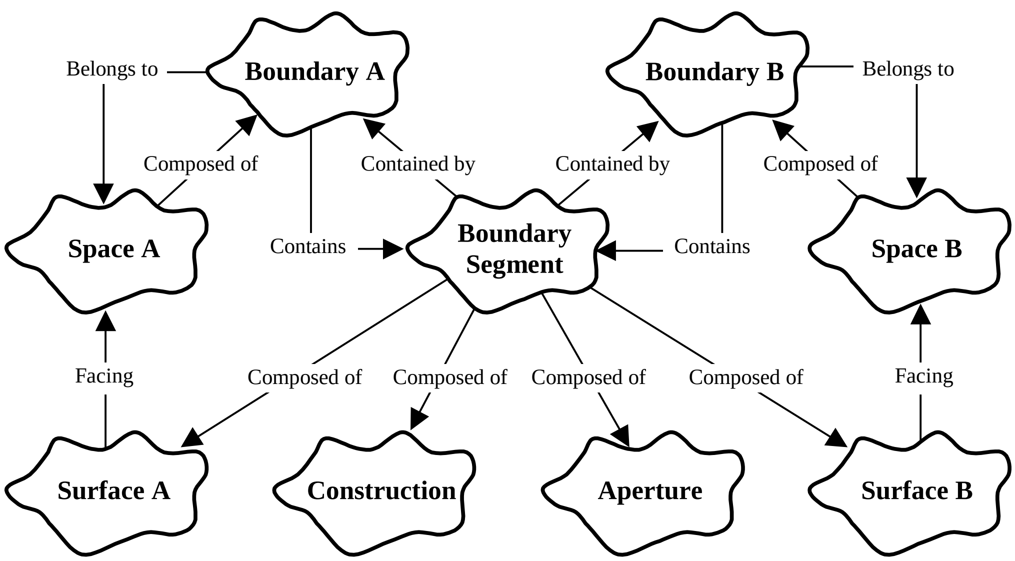


Figure 2. *A small window into the object-oriented building model used in the BDA, demonstrating the network resulting from the relations among objects.*

The object-oriented representation used in the BDA is designed to allow for flexible creation of objects, so that it can be extended to address the modeling needs of simulation tools to be linked in the future. It is based on a so-called "meta-schema," which considers *relations* and *attributes*, as well as the attribute *values*, as objects themselves. By modeling each attribute as an object, an attribute becomes more than a simple value holder. As an object, the attribute knows its name, its units, its display options (e.g., as a numeric value, as a 2-D graph, etc.) and its dependencies on other objects (e.g., simulation programs that may use it as input or output). All of this information is used to facilitate the effective communication between the BDA and the various simulation and visualization tools linked to it, through the Application Programming Interface.

The Application Programming Interface (API)

The BDA itself does not perform any simulations nor does it provide any means to initiate a building description. It merely acts as a data manager and process controller for multiple programs, such as graphic and data editors, simulation tools, databases, etc. Since the data required by each tool vary not only in content, but also in format, a “driver” is developed for each tool, which maps the generic representation used by the BDA to the specific representation used by that tool. This driver resolves any differences in format, units, and naming conventions between these representations.

The BDA uses two main methods to communicate with other applications: Active-X and input/output files. Active-X is a mechanism for exposing functions from one application to another. This is how the BDA and the Schematic Graphic Editor (described later in this paper) communicate with each other following the user's actions. The file-based approach is used to communicate with applications that are already using a file-based data exchange mechanism to receive their input and provide output.

The BDA may also access multiple databases, such as the Prototypes Database and the Case Studies Database (described later in this paper), as well as third party databases of building components and systems. Database access is achieved through the use of query languages. All data access and process controls are handled through a single generic graphical user-interface. If individual applications provide their own user-interfaces (such as the Schematic Graphic Editor), the BDA supports their concurrent use through its application-programming interface.

The Graphical User Interface

The Graphical User Interface (GUI) of the BDA has been designed to address the input and output needs of any simulation tool in a generic way, independent of display resolution. The main objectives of the GUI design were to allow building designers to

- compare *many* alternative building designs with respect to *many* descriptive and performance parameters,
- review and edit the values of input parameters in a consistent and orderly fashion, and
- select input and output parameters for review and comparison through enhanced display options.

These objectives were met by the creation of two main BDA GUI elements, the *Decision Desktop* and the *Building Browser*, as well as the Schematic Graphic Editor, which is a separate application described later in this paper.

The Decision Desktop

Decision-making among alternative design options requires simultaneous side-by-side comparison with respect to the various design considerations, which may cover any number of descriptive and performance building parameters. The Decision Desktop (or simply Desktop) is a re-sizable spreadsheet-like element whose rows may house any of the input and output parameter addressed by the simulation tools linked to BDA, and whose columns correspond to the alternative design solutions under consideration by the designer (Figure 3).

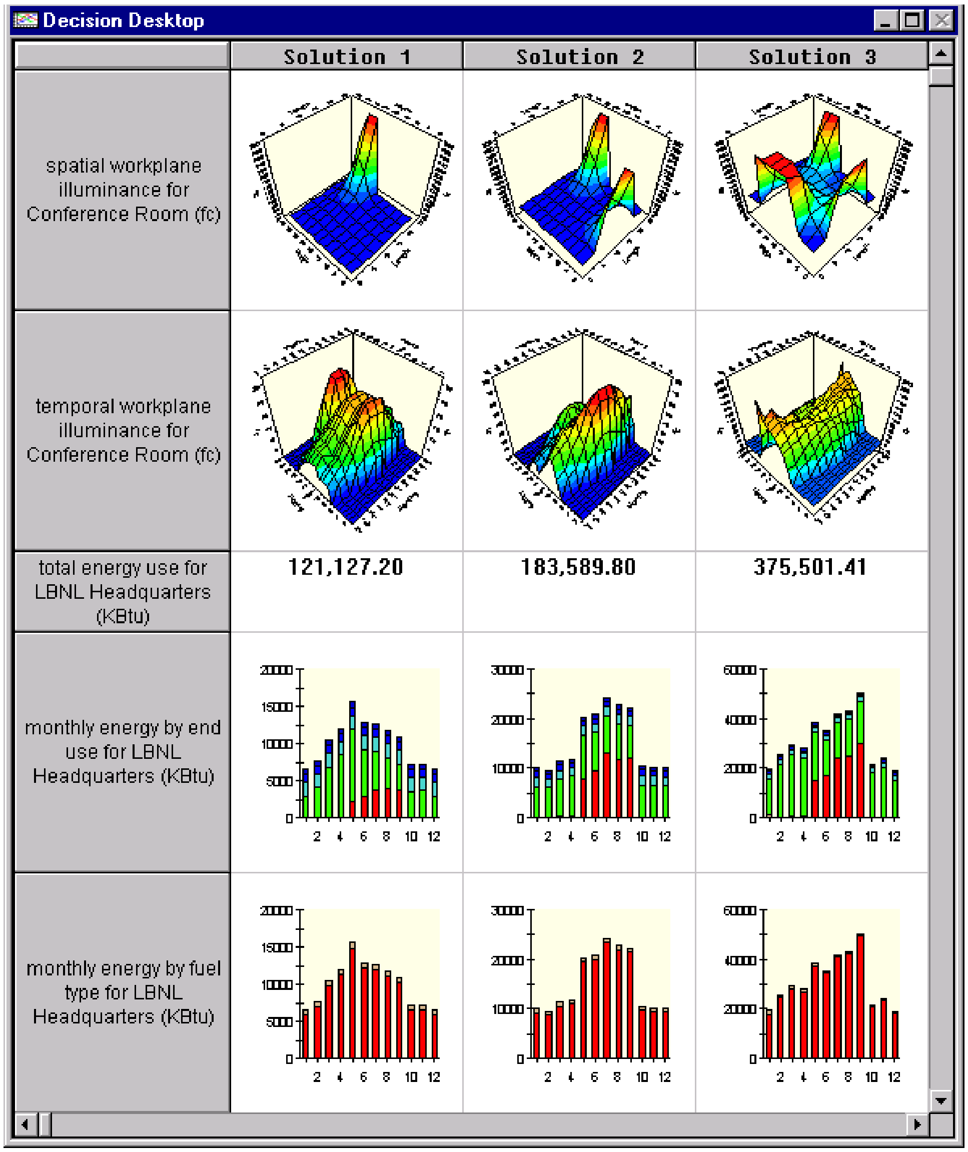


Figure 3. *The Decision Desktop allows the user to compare multiple alternative designs with respect to any number of input and output parameters addressed by the simulation tools linked to the BDA.*

The values of the input and output parameters are displayed either numerically or graphically within the spreadsheet cells. The supported value types range from single numbers to one- and two-dimensional arrays, images, sounds and videos. Any number of cells can be expanded for view in their own individual windows (Figure 4). Based on their type, values can be displayed in several different ways (e.g., 3-D graphs, contour plots, etc.), all of which are customizable by the user. The customization of display parameters can be set for any individual value (cell) or for the values in every solution (entire row).

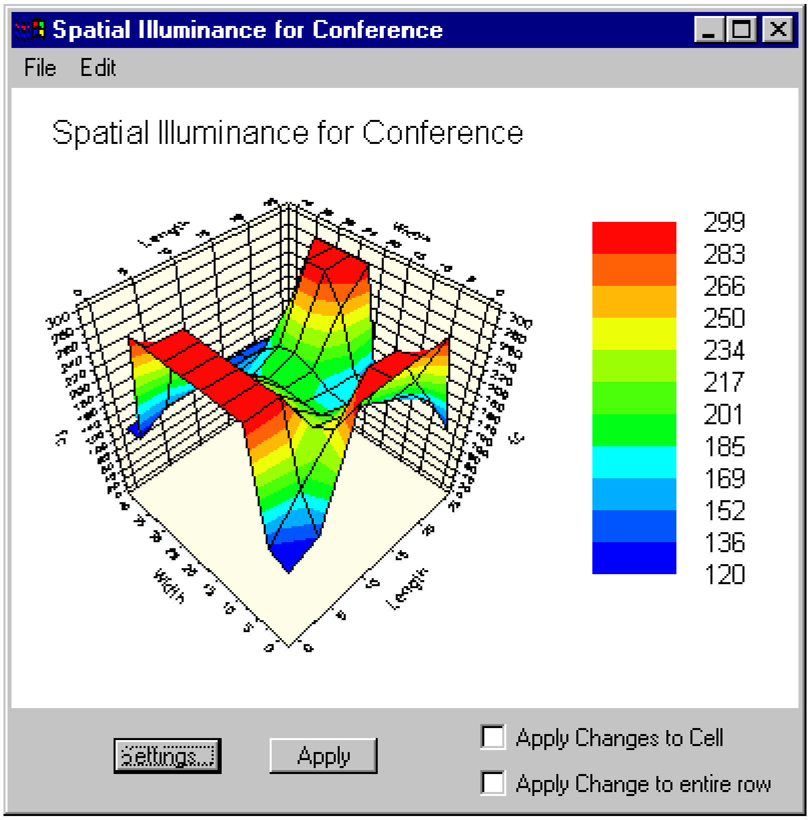


Figure 4. *Each individual data cell can be expanded for view into its own window, through which the user can modify the display options, such as view angle, caption titles, etc.*

The Desktop offers additional functionality with respect to controlling the size and sequence of its rows and columns. The user may change the size of the cells at any point. Parameters (rows) and solutions (columns) can be moved to any arbitrary location within the Desktop. Moreover, the sequence of solutions can be sorted with respect to the values of any of the displayed parameters (rows) in either ascending or descending order. If the value of the sorting parameter is an array or a matrix , then the minimum, maximum or average value may be specified as the sorting criterion.

The Building Browser

The Building Browser (or simply Browser) is a re-sizable GUI element which allows BDA users to navigate through the building representation and view the objects and parameters, along with their values, through two main window areas (**Figure 5**).

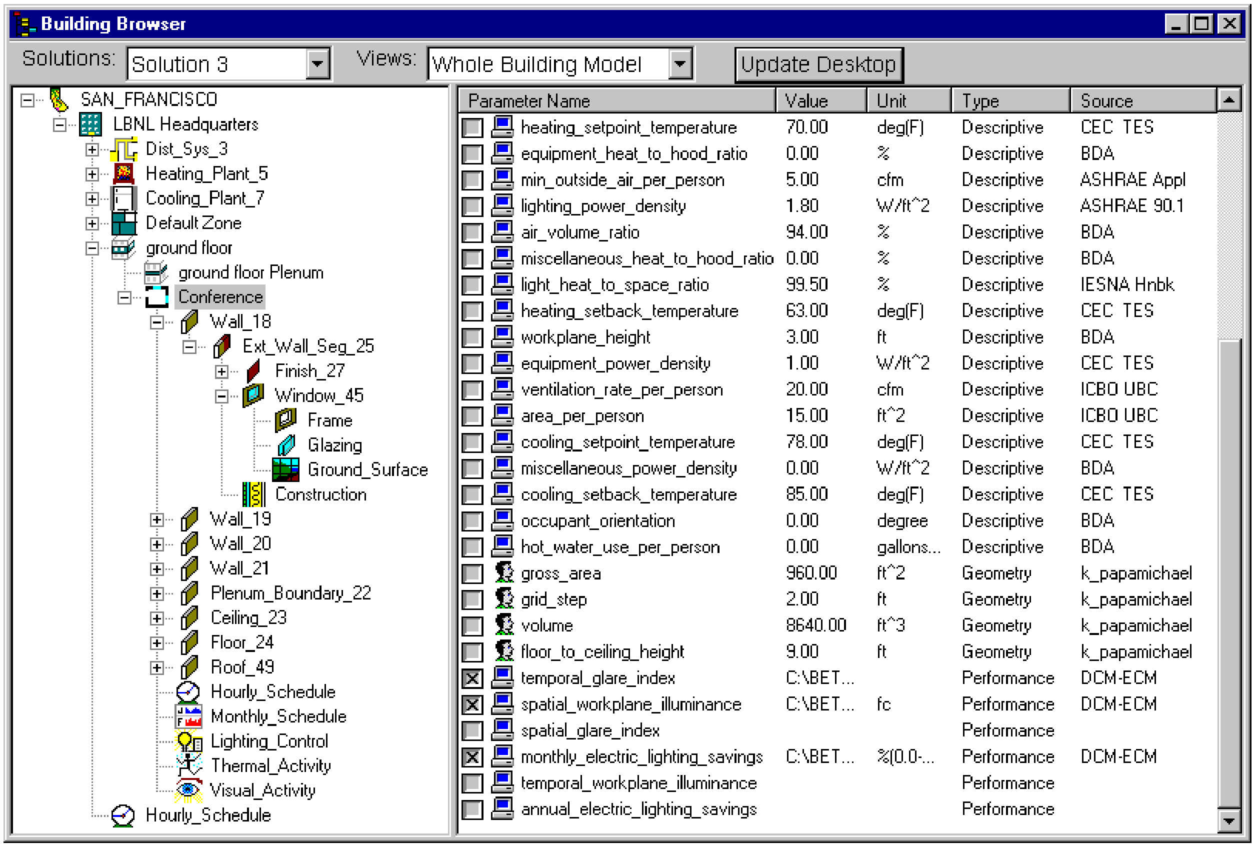
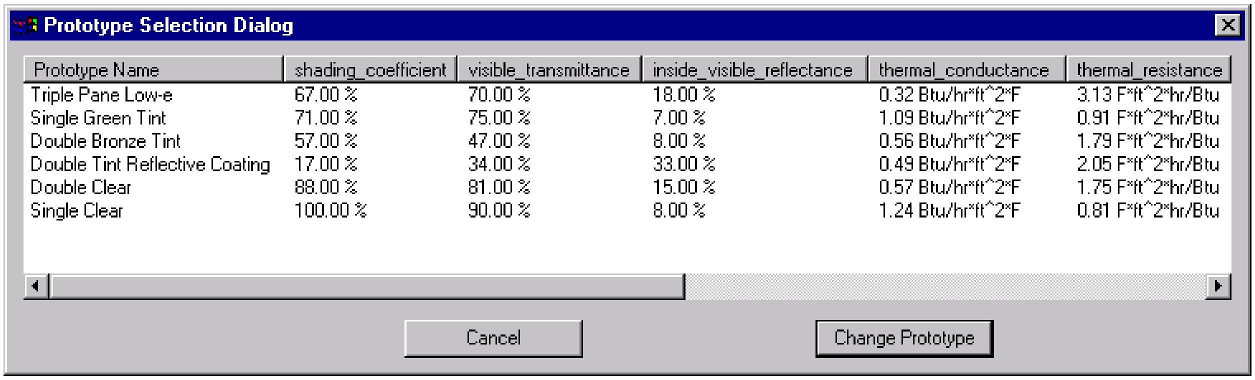


Figure 5. *The Building Browser allows the user to quickly navigate through the object-based representation of the building and its context, and select any number of input and output parameters for display in the Decision Desktop.*

The left window area essentially displays objects in an hierarchical manner. Since some building objects may be of more interest than others to a particular user, the Browser can be customized so that certain levels of the building representation are hidden. A user interested in windows, for example, can easily define a “view” that displays all the windows within a building or a zone, bypassing the space and wall objects. When an object is selected by the user in the left window (i.e., by clicking on it), its parameters that serve as input to or produced as output from the simulation tools linked to BDA are displayed in the right window area of the Browser.

BDA maintains an extendible library of alternative options for every building object. Right-clicking on an object icon, either in the left or right window area of the Browser, activates a pop-up menu through which the user can access the properties of the object and alter its value by selecting an alternative from the corresponding library of prototypes through the prototype selection dialog box (Figure 6). Right clicking on a parameter in the right window of the Browser activates a pop-up menu through which the user can access the properties of the parameter and alter its value (Figure 7).



Prototype Name	shading_coefficient	visible_transmittance	inside_visible_reflectance	thermal_conductance	thermal_resistance
Triple Pane Low-e	67.00 %	70.00 %	18.00 %	0.32 Btu/hr*ft^2*F	3.13 F*ft^2*hr/Btu
Single Green Tint	71.00 %	75.00 %	7.00 %	1.09 Btu/hr*ft^2*F	0.91 F*ft^2*hr/Btu
Double Bronze Tint	57.00 %	47.00 %	8.00 %	0.56 Btu/hr*ft^2*F	1.79 F*ft^2*hr/Btu
Double Tint Reflective Coating	17.00 %	34.00 %	33.00 %	0.49 Btu/hr*ft^2*F	2.05 F*ft^2*hr/Btu
Double Clear	88.00 %	81.00 %	15.00 %	0.57 Btu/hr*ft^2*F	1.75 F*ft^2*hr/Btu
Single Clear	100.00 %	90.00 %	8.00 %	1.24 Btu/hr*ft^2*F	0.81 F*ft^2*hr/Btu

Figure 6. *Through the prototype selection dialog box the user can change the value of a building object by providing a list of all alternative library entries known to BDA.*

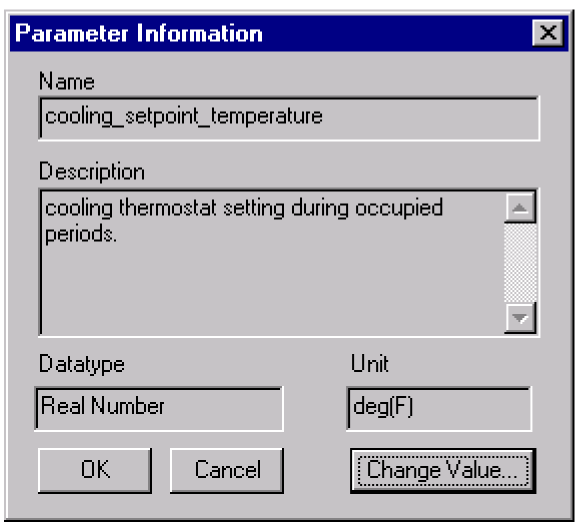


Figure 7. *The parameter information dialog box provides information about a single parameter and allows the user to modify its value.*

In addition to viewing objects and parameters and modifying their values, the Browser also serves as the mechanism for selecting the parameters (input and/or output) to be displayed in the Desktop. Any number of input and output parameters can be selected by the user simply by clicking on the check-box to the left of them (Figure 5). Clicking on the "Update" button creates a new row in the Desktop for each of the checked parameters.

Once one or more performance parameters have been selected for viewing in the Desktop, the user can request the computation and display of the values for all checked parameters by clicking on the "Calculate" button found in the main BDA window. BDA automatically prepares and submits the input to all simulation tools required for these computations, which in turn return their results to BDA for display in the Desktop.

The Schematic Graphic Editor

The Schematic Graphic Editor (SGE) is a stand-alone, CAD-like application that is provided along with the main BDA application. As explained earlier in this paper, the SGE is a separate application that can be replaced or supplemented at any point with any CAD system that uses an object-oriented representation of building components and systems. Traditional CAD programs offer a tools palette that allows users to draw geometric shapes, such as lines, rectangle, circles, etc. Although the end result may appear the same, SGE's palette offers tools to draw building objects, such as spaces, windows, etc. The SGE supports multiple alternative design solutions and displays each one in its own window (Figure 8).

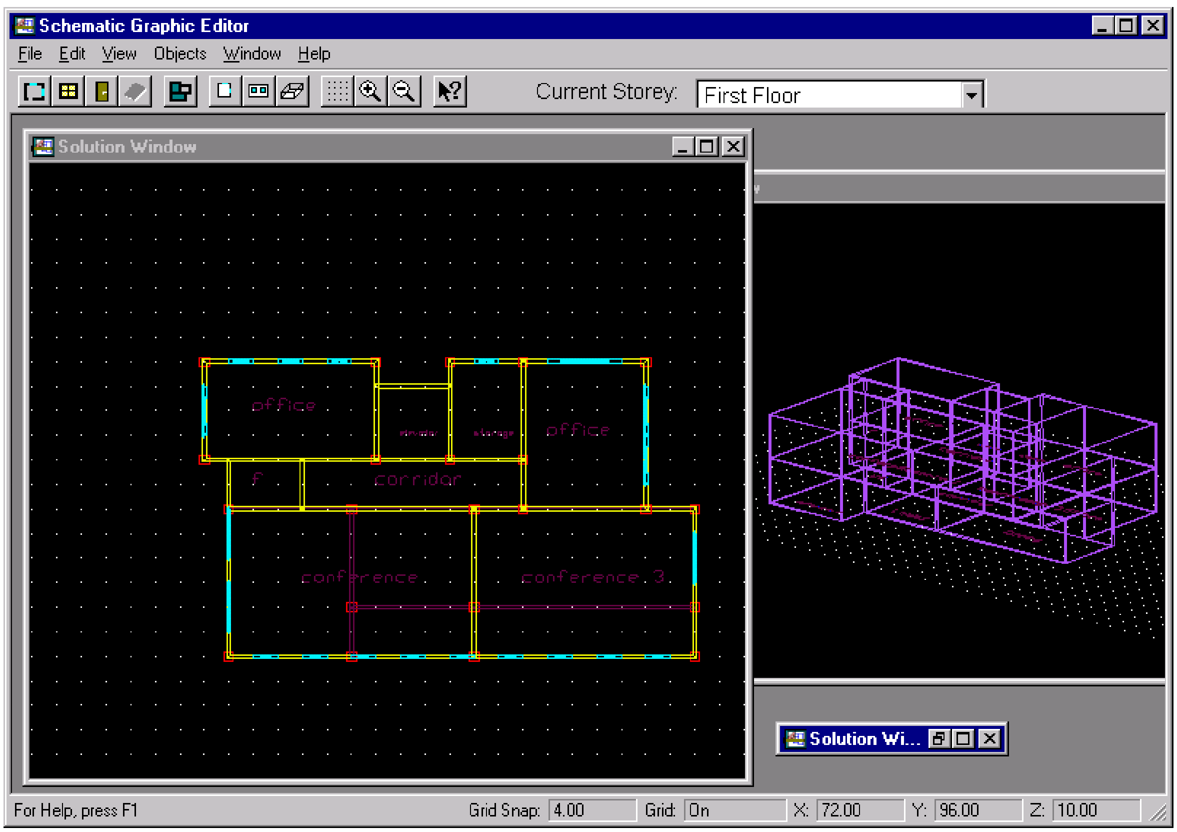


Figure 8. *The Schematic Graphic Editor allows the user to draw and modify the geometry of building objects, and supports the display of multiple design alternatives, in their own windows.*

As the user creates building objects in the SGE, the BDA continuously receives information through Acitve-X links and creates the required building objects with the specified geometry. Moreover, through a Default Value Selector (DVS) module, the BDA selects "smart" default values from a Prototypes Database (described later in this paper) to prepare a complete input for the simulation tools that are linked to BDA. When, for example, the user draws a space in SGE, wall, ceiling and floor objects are automatically generated along with default values for all required parameters. The user can of course change these default values at any time through the Building Browser.

The Prototypes Database

The Prototypes Database contains values for a complete building description required as input to the simulation tools linked to the BDA. This database is used to complement the user-defined building model by specifying context dependent default values for those aspects of the building description, which have not been directly addressed by the user. The selection of the default values is performed by a Default Value Selector (DVS) and is based on building location, building type and space type. For example, DVS selects a default exterior wall segment type by first computing the ASHRAE recommended minimum thermal resistance based on degree-days and then selecting a wall type from the library of walls that best matches the recommended value.

The Prototypes Database relies on a wide variety of industry and professional sources for its prototypical values. These sources are critical in defining common practice standards for the design and performance of today's buildings, and are thus used in creating building descriptions. Sources used for the Prototypes Database include:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) - Fundamentals Handbook, Applications Handbook, 90.1-1989 standard (with IES), etc.,
- California Energy Commission (CEC) - Advanced Lighting Guidelines, Non-Residential Compliance Manual, Technology Energy Savings, etc.,
- Building Officials and Code Administrators International, Inc. (BOCA) National Building Code, and
- Department of Energy - Energy Conservation Performance Standards for New Buildings.

Default values can also be replaced or supplemented by selections used as standard practice by any building design firm using the BDA.

The multimedia Case Studies Database

The BDA is also linked to a multimedia, Web-based Case Studies Database (CSD) with contains information about existing buildings. This is in addition to third party databases with building data, which BDA accesses through query languages. Through the available World Wide Web technologies, the CSD supports documentation of information about existing buildings in the form of text, images, sound and video (Figure 9).

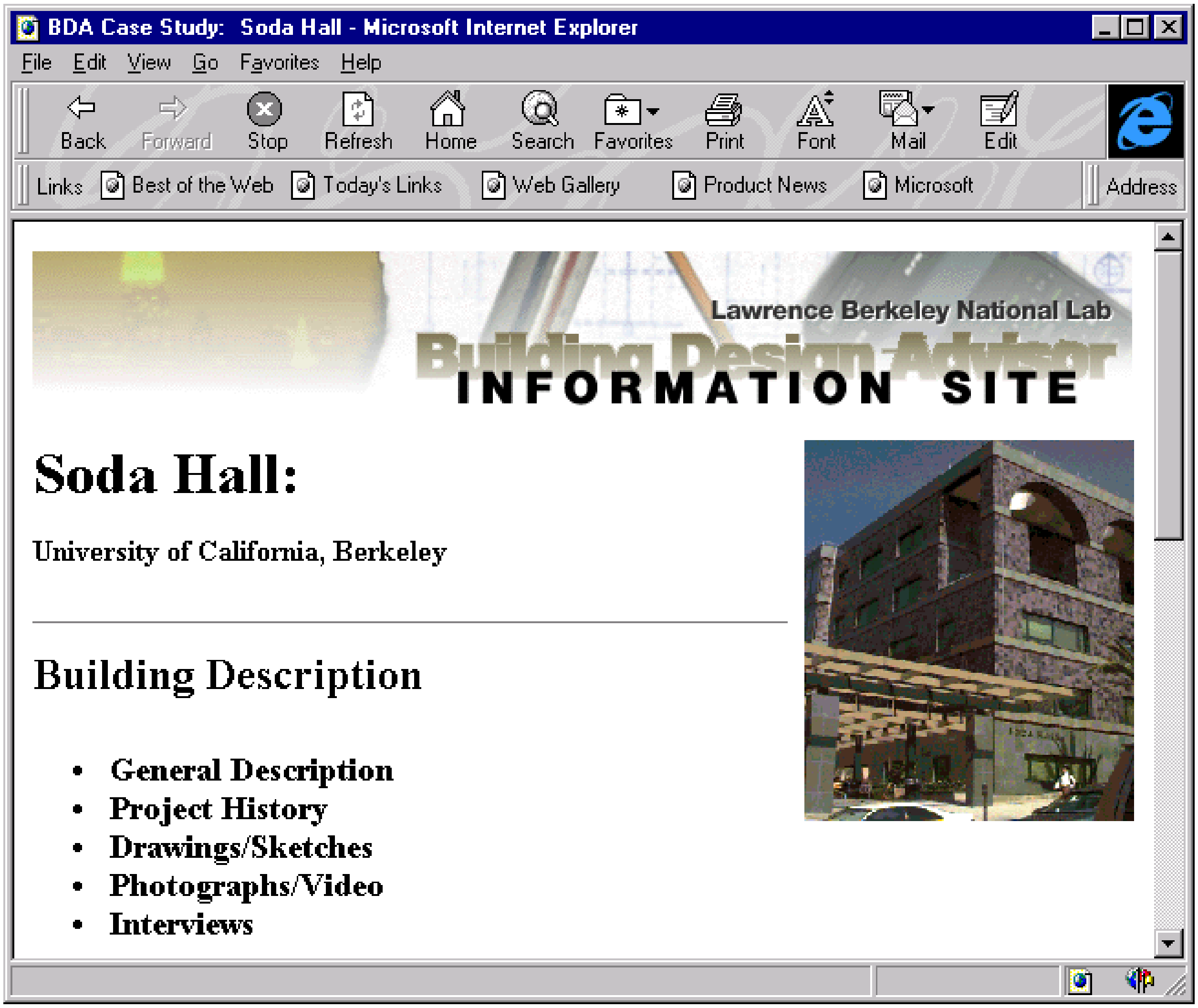


Figure 9. *The Case Studies Database allows for complete documentation of existing buildings through the use of measured data, text, images, sound and video.*

The initial version of BDA contains a small number of case studies to demonstrate the basic functionality of the CSD. The purpose of the CSD is to provide a realistic context for the specification of performance goals, as well as for the evaluation of the performance of design alternatives, through comparison to real world data. Moreover, the CSD is intended to serve as a showcase of strategies and technologies with extensive documentation on advantages and disadvantages, to further facilitate the decision-making process.

Current status and future directions

Currently, the BDA is in its beta release and includes links to the Schematic Graphic Editor (SGE), a Daylighting Computation Module (DCM) and an Energy Analysis Module (RESEM) [Carroll, et. al. 1989]. While the current version of the BDA is linked to a limited number of tools and databases, there is no intrinsic limitation on what can be connected. In a general sense, a tool is an external application, which uses some or all of the BDA building description to perform some function or service. In addition to the development of links to more simulation tools, such as DOE-2, RADIANCE and COMIS, we also envision the development of smaller tools, which may be invoked to create and edit specialized or complicated objects such as schedules, shading devices, etc. These tools will be used much the same way spell checkers and equation editors are used in word processors.

The BDA distribution will follow two main channels: a commercial one for industry, and a non-commercial one, for academia (i.e., education and research). The academic distribution will be for use in building science, computer-aided design and design studio courses. In addition to its usefulness for teaching, the BDA also offers an integrated platform for software development. It provides required database management and user interface functionality, so that students (as well as third party developers) can concentrate on the development of algorithms for performance analysis, equipment selection, diagnostics, design advice, etc. Moreover, we expect that students will also develop and submit Case Studies Databases that could then become available over the Internet.

Distributed computing and multi-user collaborative design over the Internet is a major part of the long-term BDA vision. Both data and computational processes can be distributed over local and wide area networks, while specialized additions such as multi-video conference and white/transparent board capabilities can be used for effective communication among multiple building design, construction and operation participants. We are actively seeking collaboration opportunities in all of these research and development areas while looking forward to a building industry that greatly benefits from the advancements in the information, computing and communication technologies.

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