An Integration System for Architectural Education: the CALIN project.

Dr. Luc ADOLPHE
Ecole des Mines de PARIS, Centre d'Energétique.
University of Colorado at Boulder, College of Engineering.

Abstract

The "CALIN" project (Computer Aided Learning Integration System) aims at the development of a hybrid computer aided learning (CAL) integrated system for Engineering Education applied to Energy conscious design of buildings.

Different learning strategies relying on the cooperation of different, established computer science techniques have been developed simultaneously. These techniques are ranging from algorithmic simulation, to knowledge bases in an expert system shell, graphical components in a CAD program, hypermedia to present technical information and graphical user interface (GUI). These cooperative techniques are necessary to match the complex problem solving context of building design and to encode real-life building design situations into tools to improve the skills of students or young designers.

A prototype of this CAL program is available on UNIX workstations (Sun SPARC Stations) , and can be easily ported to other computer platforms This project represents the first building-related CAL integrated system to be developed and tested in the United States and in France.

1 CALIN, why ?

In Calin, we have tried to answer to different problems met in three contiguous domains:
- the building design context,
- the energy efficient design context,
- the architectural engineering learning context.

Ecole des Mines de PARIS,
Centre d'Energétique,
60 Bvd St Michel, 75272-Paris Cedex 06,
France, fax.: (33) 1 43 54 18 98,
e-mail: adolphe@manitou.ensmp.fr

University of Colorado at Boulder,
College of Engineering,
Boulder CO, 80309-0428, USA,
fax (1) 303 492 73 17,
e-mail: adolphe@bechtel.colorado.edu

1.1-The building design context

Two main problems have been encountered in this context:

1)Important **inconsistencies** between the analytical approach on which traditional simulation tools rely and the way design is effectively conducted have been found [**Adolphe-86. Hoc-87**]. Traditional engineering evaluation programs rely on **deductive models**, or top-down approach, common in the engineering practices, defines descending levels of specification from the whole project to its parts.
Actual design involves at least two more sophisticated models, the induction and the analogy:
-the **inductive model** , or bottom-up approach, elaborates from elementary parts of the project more global ones,
-the **analogic model**, or typologic approach, tries to adapt already existing types (concepts or projects) to the new situation learned.[**Hoc-87**]

2)The second problem met in the building design context is the fact this process involves various actors of different cultures. They are currently using different languages (or dialects), and they use different tools. These tools are not integrated. Very often the inputs of one tool are not compatible with the outputs of another tool used during the design process.

1.2-The energy conscious design context

Three main problems have been encountered in this context:
1) Traditional energy evaluation tools are used solely at the end of the design process, because they rely on a quasi-complete description of the project. So fourth, they are only usable when the main choices about massing, orientation materials... have been done. Without time consuming transformations, designers cannot change these fundamental design options.
2) Traditional engineering evaluation tools use simulation programs. To improve their project designers rely on trial and error approach (or more scientifically parametric studies) which do not correspond to straightforward learning processes.

3) Professional engineering tools do not involve traditionally knowledge about the local or global effects on the building energy performance (which involves simultaneous variables like climate, environment, site, building envelope, heating, cooling and ventilation systems), or knowledge about the most appropriate and well-suited technologies. These tools are used to evaluate the performance but do not offer any guidance for designers in the improvement (optimization) of the project, and for comparison with already existing projects.

1.3- The architectural engineering learning context

Three main problems have been encountered in this context:

1) Most of the architectural engineering learning programs are relying on traditional techniques combining manual calculation, the use of CAD programs disconnected from any technical era, the use of spreadsheets to embed engineering evaluation tools... These distinct programs are not linked together in a global approach of design

2) .The architectural engineering learning programs use only few professional tools that are poorly integrated. These programs do not take advantage of the recent computer science techniques such as artificial intelligence (AI) and expert systems, hypermedia, graphical user interfaces (GUI) and CAD programs offer the opportunity to develop **integrated environments** allowing one to develop simultaneously **different learning strategies** (deductive, inductive and analogic models).

3) Traditional engineering evaluation tools cannot be used directly to improve the skills of students and future designers (see 1.2).

2. CALIN PRINCIPLES

Our approach try modestly to answer to these various problems, combining drafting in a CAD program , evaluation in an analysis method, optimization with an expert system and comparison with reference projects presented in the hypermedia.

2.1 the learning models

From a **learning model** stand-point, the CALIN project represents a hybrid Computer Aided Learning program, based on the assumption of a mix between **different models of learning**:

- **-deductive** model (by "conceptual" diagnosis of the user's project), using a steady state evaluation of the energy performance of a building project input in a CAD program,
- **-inductive** model (encoding strategies of improvement of this project), allowing the student to "optimize" a building project from a user defined strategy of improvement. This technique of improvement can be successfully compared, from the pedagogical point of view, to traditional techniques relying on trial and error approaches ,
- **-case-based** model (by analogy with reference buildings), allowing a direct comparison of the user's project with reference building projects and their energy performance.

These learning models are able to train designers in basic problem solving skills for architectural and engineering design situations, by experiential assimilation and utilization of technical concepts through practice with professional tools (e.g., a 3D-modeler) or reference codes (e.g., energy guidelines), in **"real-world" problem-solving situations**

In these various ways, the proposed project is significantly better than current approaches to energy conscious building design which use only the deductive model, the basis of traditional engineering tools.

2.2 The architectural engineering principles

From an **architectural engineering** (and architecture) stand-point, this project will help:

- -to develop a technical sensitivity and increase the conceptual value of the project
- -to allow the re-integration, in the early stages of design, of competencies and a pertinent knowledge traditionally introduced in the later stages,

-to link an architectural design with its generic energy typology,
-to practice energy conscious design through the use of state of the art energy evaluation methods,
-to allow a better understanding of the main architectural factors involved into the energy performance of a building.

2.3 The civil engineering principles

From a **civil engineering** stand-point, this project will help:
-to link the technical dimension of the project to the architectural and construction aspects of its instrumentation,
-to practice building design through the use of state of the art CAD environments,
-to enhance the architectural quality of a project taking into account considerations from outside of the narrow engineering discipline

3 CALIN, HOW ?

The strategy detailed here draws basically from recent research in three complementary research domains: artificial intelligence, graphical components and hypermedia to encode each of the learning approaches. Therefore, different "modules" have been developed and are cooperating to simultaneously perform the different educational strategies (see Fig.1). With these different modules, the users is basically able:
- to input graphically the building project (in a CAD program, Microstation, from Intergraph),
- to extract alphanumerical geometrical data (in the quantifier),
- to make an energy analysis of the project (in the diagnosis module),
- to improve the project (using an expert system),
- to compare their project to already existing, exemplary architectural reference buildings (in the hypertext).

The six modules developed for this specific project are presented below.

3.1 Construction module

A **construction module** represents the graphical description of buildings, supported by a solid modeler. This modeler will be **MICROSTATION** from Intergraph **[Integraph,1992]**. This professional 3D modeler have been chosen for its Input/Output facilities , and for its MDE development environment allowing one to have access to the 3D-modeler engine or to information encoded in the design files (see Fig. 2).
Libraries of architectural elements and tools to help designing the building project have been developed to customize this generic environment for building design.
This module allows the students to be familiar with current performing computer drafting techniques (for example, 3D primitives applied to building designs), visualization techniques (for example, hidden line perspective, smooth shading, raytracing...) and to input all the relevant topological and geometrical information about the building design project (e.g. the shape and volume of the building, the area of opaque walls, openings, the volume, the type, the status and the composition of each room or zone, their adjacencies...)

3.2 Data structuring module

A **data structuring module** filters and organizes the outputs of the construction module in a conceptual data model adapted to architectural and civil engineering evaluation of buildings. This "quantifier" linked to the internal databases involved in MICROSTATION is developed with MDL. It allows to extract all the alphanumerical information needed by the other modules (currently all the area and volume information on the project, the adjacencies between rooms, zones and floors, the orientation and the relation between elements - see Fig. 2)

3.3 Diagnosis module

A **diagnosis module** compares the known and derived information on the project with a set of constraints based on a standard performance characteristics of its components (from the ASHRAE bin method **[Knebel-83]**). This steady state calculation of annual energy consumption for heating, cooling and domestic hot water have been improved to take into account precisely the seasonal variation of solar gains **[Vadon-91]**, the conduction through slabs **[Mitalas-87]** and the air flow rate due to infiltration **[Grimsud-84]**,. The advice provided includes thermal, geometric, and other architectural and engineering concerns(see Fig.3). To help the user to compare its project to reference values, an analysis of fundamental parameters, named "**performance indices**" (like for example the compacity ratio, the overall U-value, the heating and cooling cost per floor square foot), is proposed. A grade is given according to the comparison of the performance indices to reference values, and allows to find out which aspect of the project should be enhanced first... This module is developed using C routines embedded in the Lisp Graphical User Interface (GUI) - *see part 3.6* -. It encodes the **deductive model** of learning: it allows a first diagnosis of the building performance from which a knowledge based advising module will allow later improvements .

3.4 Advisor module

An **advisor module** advises the user of the issues and the possible answers to these issues from knowledge based strategies for improvement of the project. The lines of reasoning of this expert system are based on:

- a rule-based comparison of a relevant set of parameters of the building project, with "reference" values (issued from energy regulations, existing HVAC knowledge bases, and experts' practices),
- a classification of the importance of these parameters by the mean of a relative difference compared with their reference values,
- the definition by the system (from this prioritized list of parameters) of a strategy of improvement (a list of parameters to improve, and "recipes" to help the user to modify these geometrical or technical parameters). (see Fig.3) This module is developed with the CLIPS expert system shell **[NASA-89]**. It encodes the **inductive model** of learning: the system is able to induce, from the user's building design, "optimized" projects answering to a specific strategy of improvement defined by the system. CLIPS is a rule-based expert system shell developed by NASA, with an inference engine based on the forward chaining strategy. Developed using the C language, this expert system shell can be easily embedded in our environment, and is portable to virtually any computer platform (UNIX, Macintosh, PC, VAX...).

3.5 Case history analogy module

A **case history analogy module** presents existing, exemplary projects, and allows case-by-case reasoning through an on-line access to examples of exceptional architectural projects, and their simplified technical analysis. This module encodes the **analogic model** of learning: it gives the user access to generic and energy related information on various reference buildings (four levels of energy efficient buildings are presented). This approach allows a link between a project and its generic energy typology.
This module have been developed thanks to the hypermedia and graphical abilities of AIDA **[ILOG-91]**: it offers the opportunity to specify a heterogeneous network of information (text, drawings, sounds). Our project enhances textual and graphical information on these reference buildings (from a general description of the project - location, site, year of construction..- to their energy analysis -using the simulation program and actual energy bills-), and the access to theoretical messages on these examples.

In this network, concepts (or parts of concepts) can be linked to each other by mouse-sensitive "**gates**" through explicit, implicit or structural paths (see Fig. 4): the use of hypertext allows a student **to "jump" from one concept to any other related concept**, just by clicking on a highlighted word or an highlighted part of a drawing (for example, by clicking on a window on a building plan, the user will access general information about the insulation and the transparency properties of various type of openings). This "non-linear" access of the information is essential for the appropriation of a new knowledge domain by students: **in their own way, and at their own pace.**
Theoretical messages can be combined in this context with practical training exercises. **Monitoring of student performance** in the learning process is easily performed in this environment.

3.6 Graphical User Interface

The **Graphical User Interface and Integration system manager** embeds all the other modules. Particular attention has been given to this **critical module for the appropriation of a new domain of knowledge** by young designers or students, both on the **form of the interface** ("shape filling", interactivity, graphical interface...), and on the **type of dialogue** (help in line, explanation of reasoning...).
This development environment allows fast, reusable and incremental object oriented programming of the GUI, with a quasi-automatic generation of portable computer code. Furthermore, bridges between LISP and C (or external procedures) allow direct calls to C-functions or external programs, data exchange between applications and links between objects. In this context, the GUI can play the central role of **integration system manager** in the seamless ensemble previously proposed. General databases giving default values of objects and presenting the main energy data library (climate, material properties, operating profiles....) have been integrated into the GUI, as well.

3.7 Link between the different modules

To understand **how the system is going to help learn** how to design energy efficient buildings, and **how the six modules previously presented interact with each other** , we would like to present a typical work session.

Starting with a simplified geometric design of dwellings in Microstation (the construction module), a data structuring module exports textual information (such as areas, volumes and relations between building elements) to the energy evaluation. This diagnosis module provides an evaluation of annual energy consumption for heating, cooling, and domestic water (based on an improved version of the ASHRAE modified bin method). Results from this analysis and data from the construction module are then transferred to the advisor module. This Expert System suggests strategies of improvement for the design by referring to its Knowledge Base and by recognition of patterns in the fundamental parameters of the project. The hypermedia presents messages about energy conscious design, proposes exercises using the other linked modules, and presents architectural references chosen for their pedagogical value, allowing the user to compare his project to these reference buildings.

The cooperation of these different modules, relying on advanced computer technologies, allows the student to adapt recent advances in theory of learning, and design, in a case study of the energy conscious design of buildings. This integrated environment design critique system focused in this project on the critical evaluation of building design with particular emphasis on its energy performance, could be applied, in the future, to practically any engineering discipline

4. CONCLUSION

A test period has been initiated during the 92-93 academic year in the Building Systems Program (Joint Center for Energy Management) in the Civil, Environmental and Architectural Engineering (CEAE) Department of the University of Colorado at Boulder.
The feedback of this first test run of Calin with undergraduate, graduate students and faculty have had the following consequences:
- a validation of the algorithms and knowledge bases,
- the development of a parser to filtrate and validate the user inputs,
- a partial modification of the graphical user interface, and of the file management.

After a test period at the University of Colorado at Boulder, this package will be widely distributed to other architectural engineering institutions in the States and will be translated to French (language, units and regulation), and ported on other computer platforms (MAC, PC).

The computer environment chosen (LISP, C, CLIPS and MICROSTATION) makes this CAL program expandable both to other computer platforms (PC, Macintosh, UNIX...), and to other technical domains (lighting, acoustics, structures) allowing fast application of this platform to building design in its entirety. This will allow a dissemination of this computer program not only in the schools of Engineering and Architecture, but also in the architectural engineering firms.

BIBLIOGRAPHY

***Adolphe L.** "The Technical decision Aid in the Architectural Design", Ph.D. dissertation, Paris, F, 1991.

***Boy G.A. & Gruber T.**, "Intelligent Assistant Systems: Support for integrated Human-Machine Systems", AAAI Spring Symposium on Knowledge-Based Human Computer Communication, Standford, Mars 1990.

***Dupagne A.**, "STRATEGY, a computer aided learning program in the field of passive solar architecture", Congress ECA ' 87, Munich, 1987.

***Grimsrud & al.**, "Infiltration model and terrain and shielding coefficients", Lawrence Berkeley Laboratory, 1984.

***Hoc J.M.**, "Psychologie cognitive de la planification", Sciences et Technologies de la Connaissance, PUG, Grenoble, F,1987.

***Hyde R.**, "Problems of Method: the evaluation of conceptual design for beginning students", Design Methods & Theories, Vol 23, N°4 pp.1102-1132, 1989.

***ILOG**, 1992: AIDA, MASAI, An environment for the development of graphic interfaces: User's Manual, Version 1.6.

***INTERGRAPH**, Microsation, User's Manual & Reference Manuals, Release 4.2, 1992.

***Knebel D.A.& al.**,"Simplified Enery Analysis Using the Modified Bin Method", ASHRAE 1983

***Lawson B.R.**, "The architect as a designer", in W.T. Singleton: the study of real skills, Vol 1, St Leonardgate, MTP, 1978.

***Minsky M.**, "A framework for representing knowledge", in P. Winston (ed): The Psychology of Computer Vision, New York, Mac Graw-Hill, 1975.

***Mitalas G.P.** , "Calculation of below-grade residential heat losses: low-rise residential building", ASHRAE Transactions,1987, V.93.

***NASA,**: CLIPS User's Guide, Version 4.3, Lyndon B. Johnson Space Center, Houston, TX, 1989.

***Rasmussen J. & Lind M.**, "A model of human decision making in complex systems and its use for design of system control strategies", RISO, M-2349, Roskilde, DK, 1982.

***Vadon M., Kreider J.F. & Norford L.K.**, "Improvement of the solar calculations in the modified bin method", ASHRAE Transactions 1991, V.97.

Figure 1. Integration system structure

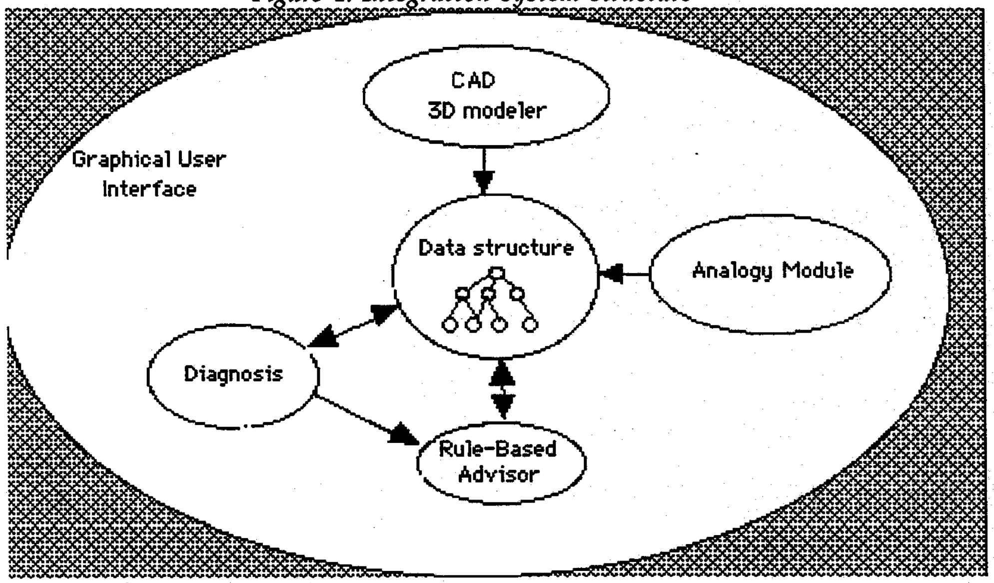

Fig. 2 ***Example of a Microstation Intergraph session and Quantifier windows***
These windows present the main tool palettes of Microstation (on the left of the screen), the command window allowing an access to manipulation and visualization tools with pull-down menus (on the top of the screen) and different views of the same building project (the right window presents a hidden line perspective of the project).
New tools have been added to the core of Microstation to allow the extraction of alphanumerical data of the project. Here a new window gives access to functions performing different volume and area calculations (for example, the conditioned area of the building, the areas of opaque walls or openings for different orientation, the type of rooms), and functions writing these data in text files.

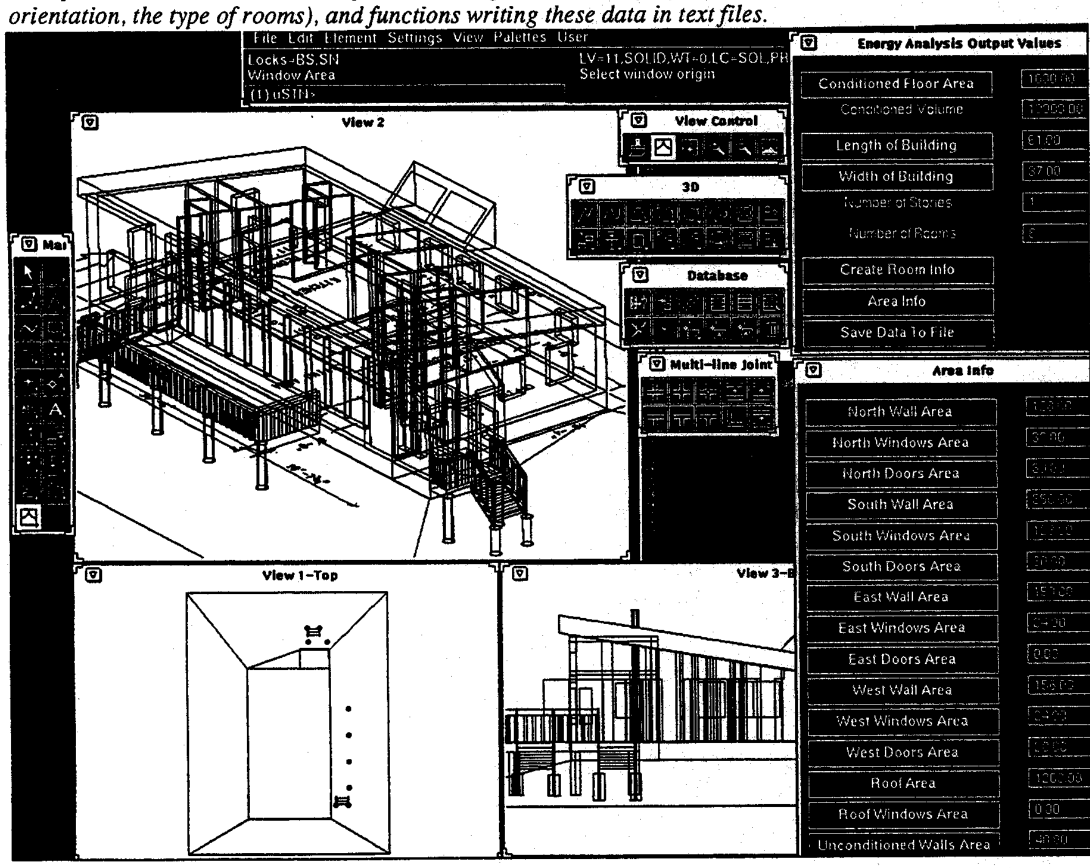

Fig. 3 Example of outputs of the diagnosis and advisor modules

These windows present the results of the diagnosis module. The main results from the bin method (transmissions, loads, and consumption for heating, cooling and domestic hot water) are given textually. Analysis of the "performance indices" of the project is given either graphically with meters (figuring the range of variation-minimum and maximum- and the value of the relevant parameters,), and textually with a grade between -2 and +2, given according to reference values comparison. This later aspect allows a first simplified expertise of the project. The advisor module outputs are presented too.

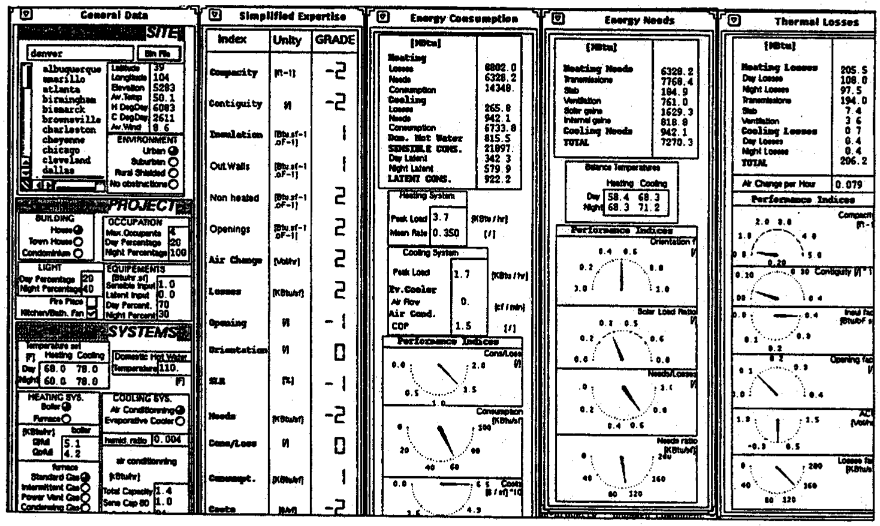

Fig. 4 Example of an hypermedia session presenting a simplified tree network (with three structural levels of information -Section, Sub-section, Page- and direct links through "gates': highlighted words or parts of the drawing)