Architectural design for energy savings and thermal comfort

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Architectural Design for Energy Savings and Thermal Comfort

Economies d'énergie et le confort thermique en architecture

Architektonischer Entwurf unter Einbezug der Energieeinsparung und der Behaglichkeit

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SUMMARY
This paper describes EKSPRO, a knowledge-based system integrating a 3-D CAD system, materials, heating, ventilation, lighting equipment, building code and occupational health regulations, as well as design guidelines user-defined by architects and engineers. It features an object oriented predicate logic knowledge representation, and interfaces to calculation packages (CAD, thermal balance, illumination, sun lighting).

RESUME
Cet article présente un système de traitement des bases de connaissance intégrant un module tridimensionnel de CAD, les matériaux, le chauffage, la ventilation, les équipements d'éclairage, les normes pour le bâtiment, les recommandations pour la santé des occupants ainsi que les régles de calcul définées par les architectes et les ingénieurs. Les principes sont une représentation logique de la connaissance orienté objet et des interfaces pour le calcul (CAD, équilibre thermique, éclairage et insolation).

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt EKSPRO, ein Expertensystem, welches ein 3D-CAD-System, Material, Heizung, Lüftung, Beleuchtung, Baunormen und Gesundheitsvorschriften wie auch durch den anwendenden Ingenieur oder Architekten definierte Richtlinien enthält. Es enthält eine objektorientierte Logikdarstellung sowie Interfaces zu den Berechnungsprogrammen (CAD, Wärmehaushalt, Beleuchtung, Sonneneinstrahlung).

1. INTRODUCTION

For project planning engineers, buildings, offices and houses, are complex dynamic objects in terms of their thermal, illumination, occupational and usage patterns. For architects, it is difficult to apprehend the consequences of alternative geometric layouts, of materials selection, of walls/window/door/vent placement, etc. . . , on thermal comfort, energy consumption (heating, cooling, ventilation), lighting and construction costs.

The consequence of this double dilemma is that most architectural designs tend to be quite traditional, based on the belief that past experience is the best reference, and/or that heating/cooling/ventilation engineering may compensate for unappropriate designs.

Furthermore, the thermal and lighting comforts depend on the usage of the construction, as well as of passive solar heating, weather and exposure. The concern for energy conservation is likely to re-emerge in the 1990's [16].

The goal is to select the layout, materials, as well as all equipments (types and locations), as to optimize jointly the thermal comfort and lighting comfort, while minimizing the total energy costs (investments, operations, maintenance), and possibly minimizing also total project costs.

This paper presents EKSPRO, a knowledge based system for architectural design in view of energy savings and thermal comfort. This system aims at fulfilling the goal stated above, while offering a fully interactive capability to both architects, project planning engineers, and equipment suppliers. EKSPRO is thus a CAAD (tool for Computer Aided Architectural Design, integrating 3-D CAD (Computer Aided Design) with knowledge bases (building code regulations, design/selection guidelines), data bases (material, windows, lighting), and calculation packages (thermal gra dient, scalar irradiation)).

EKSPRO was built by the Technical University of Denmark, for Cenergia A/S, also withDomus APS, Torben Wormslev M.A.A.cooperation.

2. SURVEY OF RELATED RESEARCH

On-going work in the CAAD area focuses on extensions of geometrical/spatial reasoning to CAD representations [1], [2], [3], [4], possibly with incorporation of generic design standards (structures, acoustics, lighting, etc.) [5], going all the way to the successive generation of designs from basic modules [6].

Other activities deal with intelligent user-interfaces to existing energy simulation, structural analysis, or other similar calculation packages, in order to assist the user in planning for a series of computation/analysis steps [7], [17], [18].

Finally, some projects concentrate on the design and configuration of the heating/ventilation/air conditioning systems for a given building layout, for tradeoffs between them [8], [19].

3. KNOWLEDGE AND DATA BASES IN EKSPRO

The data and rules used explicitly in EKSPRO are surveyed below. In the follow- ing Sections, this knowledge segmentation will correspond to knowledge worlds (KB-i), incorporating either declarative or procedural functions.

1. KB-1: Building code an occupational safety regulations:

KB-1 contains all legal, regulatory or standards constraints, originating in a diversity of official documents. Some sample rules are reproduced below in mnemonic form:

KB-1(1):	floor area ≥ 7 m^2/office
KB-1(2):	air volume/person ≥ 12 m^3 (8 m^3 when ventilation is present)
KB-1(3):	ceiling height ≥ 2,5 m (or ≥ 2 m in average for inclined ceilings)
KB-1(4):	stationary work temperature ∈ (18-25° C)
KB-1(5):	air cooling can be authorized, but only after sun screens, removal of heat/lighting sources, have been implemented.
KB-1(6):	escape window (height + width) ≥ 1,5 m, with height ≥ 0.6 m and width ≥ 0.5 m and lowest level above floor ≤ 1.2 m.
KB-1(7):	daylight factor ≥ 2%
KB-1(8):	electrical lighting factor ≥ 3%
KB-1(9):	air renewal rate ≥ 8 m^3/person/h.

2. KB-2: Architectural design and engineering knowledge

This knowledge is the hardest to acquire, but was structured into objects, object classes, attributes and attribute values, in order to comply with object oriented design principles. Table 1 gives the main objects and their properties, whereas Table 2 specifies how the attribute values are queried from data bases or calculated by application specific software modules. Price is an additional attribute for all materials.

Attached to these objects are a set of user-defined rules indicative of architectural, design or engineering practice for choices, preferences, or imperative conditions.

Example: We give below some of the KB-2 rules, for one specific use, in terms of the selection of heating/cooling sources each represented by a specific class instance.

KB-2(1):	assert (radiators and cold air)
KB-2(2):	if: office building and area > 60 m^2, then: hot air and cold air.
KB-2(3):	if: office building and area < 40 m^2, then: mechanical ventilation and hot air
KB-2(4):	if: window area > 6 m^2 and window orientation = S, E, W, then: sun screens.
kb-2(5):	if window height ≥ 1.5 m, then: radiators.

4. KNOWLEDGE REPRESENTATION AND INFERENCE IN EKSPRO

EKSPRO involves the careful selection of a knowledge representation, of an inference procedure, of a user interface, and of interfaces to external data and procedures (Table 2).

4.1 Knowledge representation

EKSPRO is characterized by heterogeneous knowledge, as well as by a generate- and test paradigm, which lead quite naturally to a multiplayer object oriented knowledge representation. Three layers are selected: level-0 for regulations (KB-1), level-1 for evaluations (KB-2), and level-3 for calculations and data bases. Furthermore, as a PROLOG environment with viewpoints was selected [10], the representations at each level will be expressed via logical predicates operating on the objects defined in Table 1 and/or on their class instances and attributes.

Details of the EKSPRO knowledge representation are found in Table 3, with illustrations in Figures 1, 2, 3; see also [11], [12].

It should be noted that the CAD-package (CAD-1), uses a wire-frame input, but stores spatial data by facets, where each facet in turn has a list of labels which contain attribute values of that facet (coordinates, size, edge-facets, material of facet, k-value of facet).

4.2 Inference

EKSPRO is based on a generate and-test paradigm, where the architect or engineer select a configuration, which is first propagated through Level 1 to generate all possible/desired occurences, and then evaluated at Level 0 for compliance to building and occupational health safety regulations (see Figures 5, 6). The attribute values are queried or calculated at Level 2, when needed during the search at Level 1, and then transferred to the conceptual graph filters at Level 0. Typically an architect would generate in CAD-1 an architectural layout, configuration and possibly some materials. The engineer would select a configuration of heating/cooling/ lighting/ materials.

Consequently, EKSPRO inference procedures are reduced to the activation of PROLOG unification and backtracking, with account, however, for inheritance properties derived from the object oriented knowledge oriented design. In this way, EKSPRO aims at constraint satisfaction in a highly unstructured user environment.

Actually, it is the user dialogue with the EKSPRO system, which by itself characterizes the reasoning process taking place. This dialogue tends to be decomposed in tasks among the following (T1-T10), called upon in an almost random order by the users (see Table 4).

For the reasons above PROLOG based explanation facilities (why?, how?) are paramount for user acceptance during all tasks T1-T10 [12].

4.3 User interface

EKSPRO belongs to the class of integrated multi-agent knowledge based systems, which allow the user to access specialized modules communicating amongst themselves while enforcing constraint satisfaction. The user must also be able to jump from one task to another (see Table 4).

The compromise solution selected in view of target environment constraints (see Section 5), is a menu based screen user interface, with DESQVIEW multi-windowing between major facilites (see Figure 4). The menu choices are currently by keyboard (digits or letters), because the end users did not yet want other devices (mouse, etc.), with the exception of their use for CAD drawing functions only. At this stage, EKSPRO offers no natural language facilities for CAD, although some research is carried out [20].

At any time, one can bind some objects, class instances or attributes to fixed values, to exclude choices on the same (Task T-6); this is easily implemented in PROLOG by binding variables or freezing predicates [10]. The material choices, object graph, class instances, and attributes can be displayed as trees or graphs of any time.

At any time also, the MS-DOS, PROLOG og PASCAL editing facilities can be called upon to edit all parts of the EKSPRO knowledge bases.

4.4 Reporting facilities

Every search (Configuration-Query) will be concluded by a report listing all possible configurations (assignment of values (classes/attribute) to objects) along with characteristic values of ΔT and heat-loss for each of them. At the end the report contains a list of values preset by the user, and therefore not included in the search.

5. IMPLEMENTATION ENVIRONMENT

Although this implied a number of major technical restrictions, EKSPRO was developed on a VAXMATE PC/AT/MS-DOS to obey with end user requirements. The main argument was that such an environment (and its price) were the maximum architects and building engineers would accept (outside a few large consulting or projecting companies).

The languages used were Prologia PROLOG-II [10] (interpreter, and soon compiler), Microsoft PASCAL, Ecosoft SCRIBE Modeller. The interface module SPECALC was extended to extract spatial/geometric attribute values from the files generated by SCRIBE. Interface modules were programmed between PROLOG II and all PASCAL modules and data bases (see Table 2).

EGA colour graphics were used, and a two monitor system is considered to accomodate the DESQVIEW windows on two screens, essentially CAD drawings on one, and user selected screens on the other.

All text is written in Danish, which explains why no screen displays are presented in this paper.

6. CONCLUSIONS

EKSPRO represents both a concept and a tool for knowledge based CAAD for architectural design in view of energy savings and thermal comfort. The migration to more powerful and user friendly implementation environments is rather straightforward, thanks to the selected tools, knowledge representation and the knowledge acquired.

Functional enhancements would cover report generation, heating/ventilation equipment configuration rules, better price calculations (with price sensitivity and ranking capabilities), and the addition of filing utilities for building block modules. Better calculation modules may also be necessary (e.g. variations of indoor temperature, thermal simulation, electrical lighting).

Current satisfied users have also expressed desires to expand EKSPRO domains to encompass choices involving static structure calculations, building acoustics, building maintenance costs, and colour selection of walls.

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Object	Class	Attributes	Calculations or data base
Architectural shape	Esthetics Surface of windows Volume	Shape Surface Volume	CAD-1 CAD-2 CAD-2
Building utilization	Office School Apartment bldg Hospital	Persons/m2 Thermal emissions from electrical equipment Lighting level Day lighting Length Width Height	CAD-3 CAD-3 CAD-4 CAD-4 CAD-2 CAD-2 CAD-2
Fire safety	Direct escape routes Indirect escape routes	Window surface Door surface Height of window Smallest window dimension	CAD-2 CAD-2 CAD-2 CAD-2
Day light	Top light Window light Reflected light	Light intensity	CAD-4
Electrical light	Area lighting Spot lighting	Intrensity Power Thermal effect	CAD-5 CAD-5 CAD-5
External wall	Table of external wall materials and type	k-value Thermal accumulation Internal reflectance External reflectance Orientation Length Width Area	CAD-6 CAD-6 CAD-6 CAD-6 CAD-2 CAD-2 CAD-2 CAD-2
Internal wall	Table of internal wall materials and type	same as "external wall"	CAD-7 CAD-2
Floor	Table of floor materials and types	same as "external wall"	CAD-8 CAD-2
Ceiling	Table of ceiling materials and types	same as "external wall"	CAD-9 CAD-2

Table 1. Objects and properties: price is an additional attribute for all materials (Viemose and Spiele price catalog): the class instances are not given above, but correspond to specific instances, e.g. of materials etc., from the data bases.

Object	Class	Attributes	Calculations or data base
Windows	Table of window materials	k-value	CAD-10
		Thermal transmission	CAD-10
		Orientation	CAD-2
		Height	CAD-2
		Width	CAD-2
		Area	CAD-2
		Position in wall	CAD-2
Sun screens	Internal screens	Sun screen factor	CAD-11
	External screens	Light screen factor	CAD-11
		Usage	CAD-4
Air infiltration	Air mass	Air flow	CAD-12
Mechanical ventilation	Air mass	Air flow	CAD-12
Heating/cooling	Radiators Cold air Hot air Ceiling irradiation Floor heating Radiators and hot air	Effect (W/m^2)	CAD-13
Thermal confort	Dimensioning heat loss	Heat loss (kW)	CAD-14
		Time constant (h)	CAD-14
	Dimensioning ventilation	Ventilation effect (kW)	CAD-14
	Dimensioning cooling	Cooling effect (kW)	CAD-14
	Energy demand	Heating effect (kW)	CAD-14
		Lighting thermal effect (kW)	CAD-14
Outside environment	Noise	Light Radiance (W/m^2)	CAD-15
	Lighting (direct)	Albedo	CAD-15
	Lighting (diffuse)		
	Lighting (reflected)	Wind speed	CAD-15
	Albedo	Air temperature	CAD-15
	Wind		
	Air temperature		

Table 1. Objects and properties: price is an additional attribute for all materials (Viemose and Spiele price catalog): the class instances are not given above, but correspond to specific instances, e.g. of materials etc., from the data bases.

Table 2: Data bases and calculation packages

Calculation on data base	Purpose	Implementation
CAD-1	3-D architectural CAD	SCRIBE Modeller system [14]
CAD-2	Calculation of geometrical attributes from CAD-1	PASCAL routines [9]
CAD-3	Building utilization data	Data base
CAD-4	Lighting calculation	SERILUX system [15]
CAD-5	Lighting source data	Data base
CAD-6	External wall data	-"-
CAD-7	Internal wall data	-"-
CAD-8	Flor material data	-"-
CAD-9	Ceiling material data	-"-
CAD-10	Window material data	-"-
CAD-11	Screen data	PASCAL routines [9]
CAD-12	Ventilation system data	User selected
CAD-13	Heating system data	PASCAL routines [9]
CAD-14	Thermal comfort	PASCAL routines [9]
CAD-15	Outside environment	TRY climatic data base and SUNCODE
CAD-16	Total price calculation	PROLOG routine cumulating the prices of all materials, using CAD-2 and CAD-17
CAD-17	Price list of all materials	Viemose and Spiele price catalog

Table 3: EKSPRO knowledge representation

Level	Knowledge-base	Knowledge representation
0 (see Figure 1)	Building code and occupational safety regulations (KB-1) (see Section 3.1)	Conceptual graph of the objects in Table 1, with logic filters applicable to each arc, and text label attached to each arc [13]: Generic predicates. arc(obj–1, obj–2, filter (1,2), "text (1,2"). filter (1,2): – F(attributes (obj–1), attributes (obj–2)). where: – "text (1,2)" is the text of the building code applying to the relation between obj–1 and obj–2 – F is the predicate value of a function of the attribute values, as fixed by the codes (see KB-1) – arc is the arc predicate
1 (see Figures 2 and 3)	Architectual, design and engineering knowledge (KB-2) (see Section 3.2)	Predicate frames attached to objects from Table 1; the class instances are represented by logical t- uples [10]; the attributes apply to all class instances of the object; the attribute values are calculated as set-forth in Table 2; the class instances are instances of all classes in Table 2. Generic predicate: is-a (obj, class). t-uples <class, class-instance)(list)>. attribute (obj, attribute-list) where: – is-a, is the class definition predicate for the objects of Table 1 – class-instance, is the list of class instances – attribute-list, is the list of attributes in Table 1, calculated as indicated in Table 2
2	Data bases and calculation modules CAD-1-16 (see Table II)	Procedures (PASCAL or others), and data structures of Table II; this includes the geometrical facet representation of CAD package CAD-1

Table 4: User dialogue tasks as related to inference

T1	Check the design process completion by jumping between screens and verifying them
T2	Evaluate the choice of alternative materials, heating/cooling/ ventilation/lighting sources
T3	Comply with code-defined, or user-defined, dimensional constraints (room temperature, heat loss, . . .)
T4	Comply with qualitative, building code or practice relations, to identify ranges of class-instances or attribute values
T5	Update the CAD layout interactively
T6	Exclude some objects or classes from the design choices, by logical binds applying to them
T7	Calculate the ventilation, lighting and other conditions
T8	Search for window sizes and room depths
T9	Configure heating/cooling/ventilation system, in terms of modules and subsystems compatible with one another
T10	Select material price classes on the basis of total construction price (e.g. cheap and expensive design alternatives)

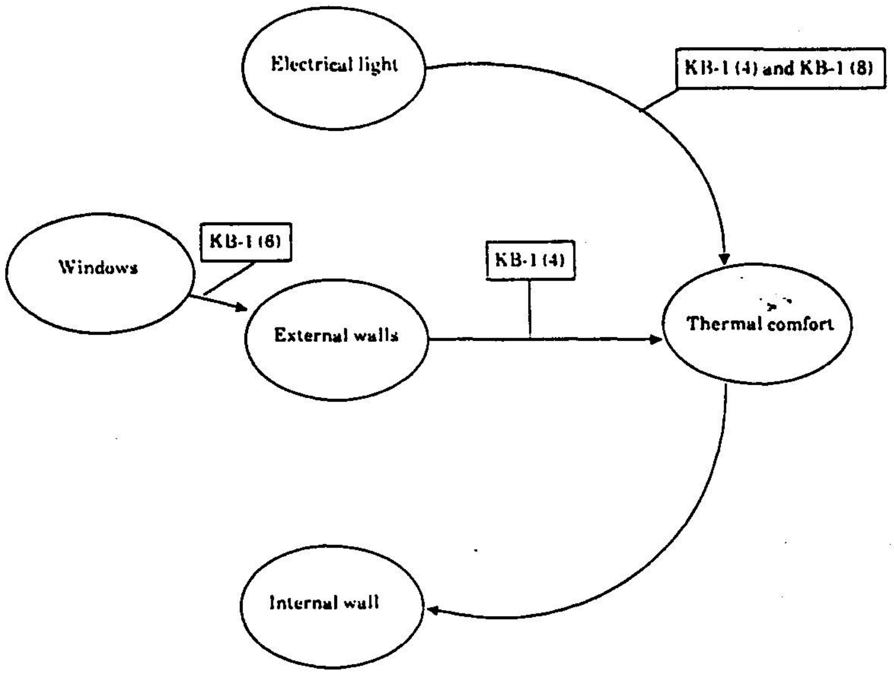


Fig. 1. Conceptual graph example (Level 0); this graph describes causal relations between objects, especially influences of one object on another, and displays building code regulations (KB-1) applicable to such relations. These KB-1 regulations appear as labels attached to each arc (see Table 3).

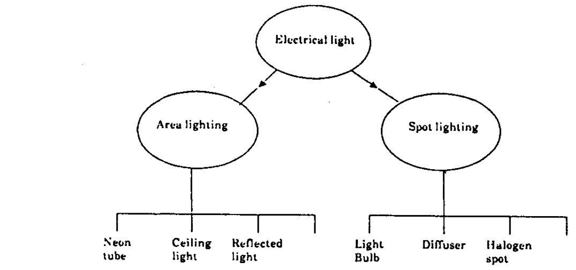


Fig. 2. Classes and object inheritance; the class-instances are the alternative types of occurence of the object.

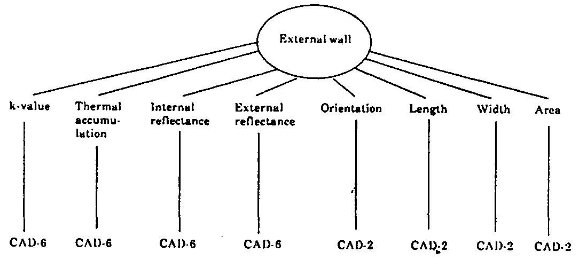


Fig. 3. Attribute-list t-uples.

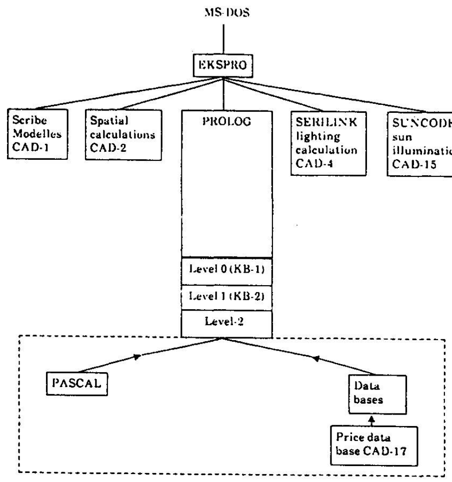


Fig. 4. User interface and major facilities available by multi-windowing.

Figure 5. **Semantic Levels**

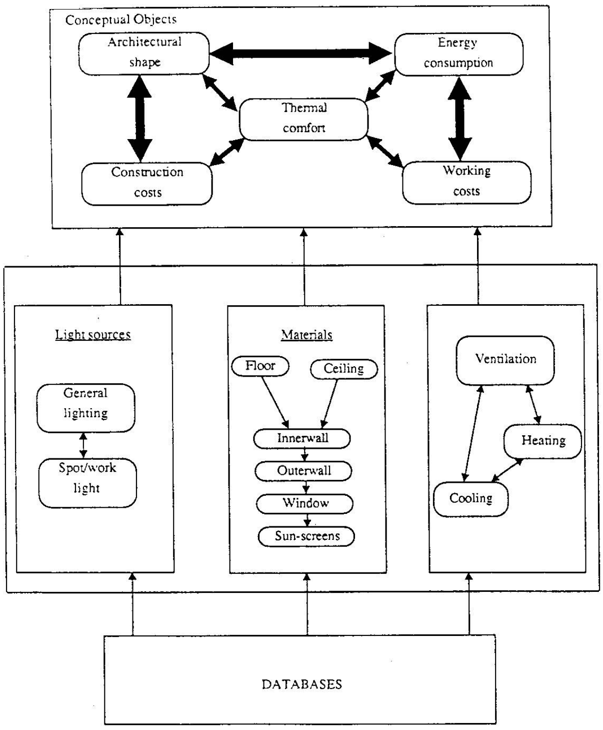
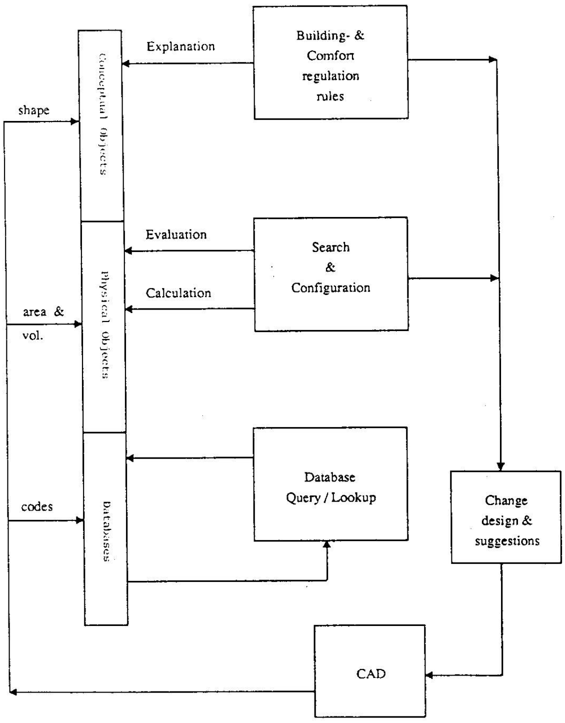


Figure 6. **Operational Levels**



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