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OBJECT ORIENTED APPROACH APPLIED TO CONSTRUCTION

Marc BOURDEAU
Centre Scientifique et Technique du Bâtiment (CSTB)
Boîte Postale 21
06561 VALBONNE Cedex, FRANCE

ABSTRACT

Knowledge representation through object oriented approaches is inducing more and more applications for construction in European countries. Such a formalism allows to describe and handle intricate structures of objects, and to express and maintain several kinds of constraints upon these objects. In this paper, we draw a survey of the French works including this approach, in order to show the various levels of implementation. We also present the studies carried out at the SCIENTIFIC and TECHNICAL CENTER for BUILDING (CSTB), in France, focusing on applications to building thermal analysis, developed using two computing tools issued from research laboratories : on the one hand, an expert system shell (SMECI), dedicated to engineering design problems and implementing an object oriented formalism to structure its knowledge base ; on the other hand, a software (ROSALIE) designed for elaboration of data conceptual models, and based on an entity-relationship formalism improved by object oriented concepts. Finally, we mention how SMECI environment has been used to implement a new kind of design expert system for specification contentment in engineering.

1. Introduction

Object oriented representation methods constitute one of the answers brought by Artificial Intelligence research to the problem of knowledge representation.

The concepts of the object oriented programming are born twenty years ago with the SIMULA language. Remained without application during many years, they were re-discovered, fifteen years later, thanks to the coming out of the famous SMALLTALK.

Contrary to the procedure oriented programming, programs are not shared into procedures and data, but organized around entities called objects, which have a double aspect of procedures and data. All the actions come from messages sent between objects. For instance, in a graphic application, a window can be represented by an object able to answer a message like "display window".

Conjunction of specific research on knowledge representation techniques, and work on object oriented programming, has lead to the development of so-called object oriented representation methods. These methods use the concepts of the object oriented programming, no longer as a simple program writing formalism, but as a genuine knowledge representation language.

Object oriented representation methods have received numerous names : schema, frames, scripts, prototypes, actors, etc. They are all languages that derive from the same representation concepts allowing the description of complex entities through the structuration of their properties.

Today, knowledge representation through object oriented approaches is inducing more and more applications for construction in European countries, especially in France.

In this paper, we draw a survey of the French work including these approaches, and present the various studies carried out at the SCIENTIFIC and TECHNICAL CENTER for BUILDING (CSTB).

2. Applications of object oriented representation methods to the building field

The need for an appropriate data description and handling language has been emphatized in several studies related to computer-aided design systems [1]. The building world, inhabited with intricate structures of objects linked together by various relations, is probably one of the domains for which this need is the most acute. It should be noticed, however, that the extension of such a language to other tasks, like plant diagnosis or project management, has been considered too.

An extended presentation of the object oriented approach concepts can be found in numerous papers [2]. We want there to summerize some of their advantages, in connection with building application :

- the concept of class allows to describe pre-defined object (or case) models, which corresponds to the common design process approach that consists in gathering components from well-known catalogued types. For instance, every time that an architect creates or modifies a wall, he wants the possibility to refer to its basis, its axis or each of its faces ; so, in his mind, he associates to every wall a set of notions that constitute a specific model for this wall ;

- the hierarchical structure of the classes, apart from the fact that it allows to lighten the description of sub-classes thanks to inheritance mechanisms, reflects the common design process consisting in progressively refining the definition of an object by attaching it to more and more precise models ;

- links between objects are settled by creating new classes or adding particular properties to existing classes. Dynamical constraints associated with relations can be expressed through functions attached to the linked objects. For instance, in order to express that a lintel must be associated to every opening in a wall, one possible solution consists in creating a facet "if-added" to the slot "list-of-openings" of the object "wall", and associating to this facet a procedure for creating a new lintel. This important aspect of constraint management requires pieces of software outside the data when a classical relational data base approach is used.

3. Outline of French research

The last CIB-W78 meeting in London (september 1987) has confirmed the development of several projects involving object oriented approaches. These approaches are used as a knowledge base implementation support, or as an interfacing language between a classical data base and application softwares. They also appear, more and more often, as a privileged tool for the definition of conceptual data models of integrated building data bases, independently of the practical solutions for the implementation of these bases.

Some of the French research works are briefly described below.

a/ The GAMSAU (Groupe d'Etudes pour l'Application des Méthodes Scientifiques à l'Architecture et à l'Urbanisme), jointly with the GRTC (a CNRS's laboratory) and the IIRIAM (Institut International de Robotique et d'Intelligence Artificielle de Marseille), is developing à CAD expert system for architectural design. The first phase of this project, named TECTON, is achieved. The architect's knowledge is modelled by means of an object oriented representation method [3].

b/ Another GAMSAU's team, in collaboration with the same CNRS's laboratory, is developing a CAD system, named DESBAT, organized around a data base machine and a functional data definition language. An object oriented data model allows to build specific interfaces between this kernel and the applications. The first choosen applications deal with the elaboration of the building specifications and the management of the urban heritage [4].

c/ The CIMA (Centre d'Informatique et de Méthodologie en Architecture) has been the leader of a CAD system project, named X2A, meant to integrate a set of technical and economical valuation modules around a common project data base. Object oriented mechanisms are included in the data definition language. The first phase of this project has been achieved in 1986 [5].

d/ The CAOMIP (Centre Régional de CAO Midi-Pyrénées), in partnership with two laboratories of the Architecture School of Toulouse, has launched the development of a CAD system, named KRÉPIS, for aiding to the architectural project. It is composed of a set of working stations linked together by an Information Management System that operates data exchange between the working stations and guarantees the global coherency between the different views. These working stations are dedicated to various professionals (architect, thermal analyst, etc.). The design of the Information Management System will use an object oriented language [6].

e/ The IIRIAM is developing an expert system for aiding to thermal analysis. The building data and the expert knowledge are modelled with an actor language, a kind of object oriented representation method.

f/ DUMEZ BATIMENT is an example of a large construction company having formed a partnership with a software company, COGNITECH, in order to build an expert system prototype for aiding to the design of the PERT network applied to works management. An object oriented formalism is used for describing the various objects [7].

Nearly all of the previous research works have been partly supported by the public authorities in the framework of the IN.PRO.BAT program.

4. Research carried out at CSTB

The CSTB has been one of the first research organisms to take interest in the possible contribution of Artificial Intelligence tools to French construction.

We present there the main research works undertaken these last two years and related to object oriented representation methods.

4.1. Object oriented approach in expert systems : the example of SMECI

A general assessment is that the use of expert systems can improve the efficiency of the design process. Indeed, the analysis of existing systems shows that CAD softwares are mainly used as drawing toolboxes or as tools for validating or completing already designed projects. Concerning the construction field, a great deal of technical softwares used by architects or design engineers, for instance in Structural or Thermal analysis, are suited to check the good designing of a given work with regard to its destination or to the regulation context, but do not actually participate to its design (in particular, they do not propose alternatives in case of failure). Intelligent knowledge based systems, such as expert systems, can fill this gap by aiding designers in defining the project specifications and elaborating the possible solutions.

Reasoning on structured objects, such as those found in building design process, has proved to be critical with first-generation expert systems in which the knowledge bases are simply composed of production rules. That is the reason why most knowledge bases of second-generation expert systems are based on a double representation formalism : on the one hand, object oriented approaches, on the other hand, production rules.

4.1.1 Main features of SMECI

SMECI (Système Multi-Expert de Conception en Ingénierie), which has been developed by INRIA (Institut National pour la Recherche en Informatique et en Automatique), and is now available on the market, is the leading French representative of this new class of expert systems.

The main characteristics of SMECI proceed from an analysis of the engineering design process. This analysis shows that, most often, designers have to coherently assemble elementary objects which can be, either completely determined (catalogued objects), or partially known, some of their attributes taking values within precised ranges. At the beginning of a project, these collections of elementary objects are vaguely defined inside the few alternatives considered by the designing team. The essential stake of the design process is to precise the description of the objects which constitute the alternatives hold as the most interesting. In general, that induces to detect the bad choices as soon as possible, to give up the corresponding alternatives, and to push the study of the possible alternatives, beginning with the one appearing the best, but keeping the possibility to go backwards at each step. The design process is closed when the designer has at his disposal a set of alternatives described enough precisely to be subjected to companies. These alternatives, solutions of the design problem, respect the specifications and the constraints of the project, and can be ordered following a criterion whose choice depends on an agreement between the building owner and the main contractor : cost, achievement time, reliability, etc.

SMECI proposes knowledge representation tools, and a treatment mechanism allowing to simulate the behaviour of expert designers, going as quickly as possible towards the best choices.

SMECI has been written in Le_Lisp, the French Lisp language. Today, it runs under various operating systems among which VMS (DEC/VAX) and UNIX.

4.1.2 Applications to building design problems

The CSTB has developed several applications with SMECI environment. Some of them have been presented in details in other papers [8]. In this article, we want to emphasize the aspects related to the object oriented representation formalism.

In the application that deals with the thermal design of dwelling buildings, the problem is to determine the characteristics of building envelop components so as to reach user-defined heat losses (G-coefficient) and/or heating needs (B-coefficient). Most often, the user will take the regulation values for these coefficients. The parameters to be precised are the following :

- the position of the heat insulation (internal/external) ;
- the thickness of the insulating material ;
- the position of the windows (interior/exterior plain of the walls) ;
- the type of the glazing (single/double) ;
- the air-gap thickness in case of double-glazed windows ;
- the type of the window-frames (wooden/metallic) ;
- the type of the window-openings (leafed/sliding) ;
- the characteristics of the wall-window junctions (with/without insulated return), when the windows are not placed in the insulated plane of the walls.

For each parameter, the possible values are taken from pre-defined lists. All the other data required for computation are considered to be fixed along the entire design process.

In SMECI, the object oriented representation formalism allows to describe all the possible models of the elementary objects whose collections will be achieved during the design process. This modelling is performed by use of categories and prototypes (Figure 1).

A category, such as JUNCTION-OF-EXTERNAL-WALL-AND-WINDOW-FRAME, represents a class or a family of objects which are of the same type and have the same properties. A prototype, such as JUNCTION-OUT-OF-INSULATION-PLANE, precises a model of objects belonging to a given category. The prototypes attached to a same category are hierarchically organized, i.e. a prototype has to precise the one which is its father. Typified properties can be associated to categories. A particular type, called method, allows to attach a computing procedure to a property (for instance, the k-coefficient, standing for the lineic heat loss coefficient of a junction). Such a procedure can call for an external function, written in Lisp or in any classical compiled language (FORTRAN, PASCAL, ...), eventually settling links with existing programs. Properties can receive value constraints whose coherency, within the hierarchical structure of a category, is automatically controlled by SMECI (see the description of the category LAYER).

A particular use of the production rules is to generate alternatives corresponding to the various possible choices for a parameter not yet valued. In some cases, depending on the modelling, this will consist in assigning particular values to object properties. In other cases, this will consist in attaching more precised prototypes to objects. For instance, a rule operates a branch for the glazing type, i.e. it creates in parallel two alternatives that differ by the type of the window-glazing (single or double). So, the system progressively builds a state tree where each branch corresponds to a design alternative, and the leaves are either solution states, or states violating certain constraints.

Figure 2 shows an example of a state tree for an upper-storey flat, electrically heated and located in Western France. The values of two design parameters (position of the windows, type of the openings) have been specified at the beginning. The solution states are grey-filled. It must be noticed that each state is valuated by a number, which quantifies the margin between this state and the target, i.e. the objective G and/or B-coefficient. This valuation is achieved by means of a computation method freely defined by the application designer. It allows SMECI's inference engine to follow a "best-first" search strategy, promoting the exploration of some branches (the "best" one), then backtracking and giving attention to others. The valuation function is an important part of the expert knowledge, because it determines how rapidly the solutions are reached.

SMECI's environment has been also used by the CSTB, in collaboration with the INRIA, to implement a new design expert system approach based on problem specifications. The basic principle of the system, named ABS (for "Architecture Basée sur les Spécifications", i.e. specification based architecture), consists in considering the design process as a sequence of changes of specifications. Specifications are described in the static part of the system, and their changes are taken over by the dynamic part.

A specification is modelled by an object. It has several properties, among which :

- the command, which represents the order given with a view to satisfying a certain need. For instance, a command can be : "to satisfy the regulation related to thermal losses", or "to achieve a given energy performance". Generally speaking, the command requires the satisfaction of a function ;

- the environment, which describes the set of constraints to be respected when solving the specification. The role of the dynamic part of the expert system will be to modify this environment so as to satisfy the command. These environment constraints are represented by objects.

It must be pointed out that the author of a given specification may be either the user, or another specification.

The functions that can be satisfied are hierarchically organized : if the designer asks for the satisfaction of a function that is decomposed into sub-functions, the system will try to satisfy the latter. In case when a function has no sub-function, the task attached to this leaf function is launched, i.e. a set of production rules are activated.

This new approach has been applied to thermal design of buildings. Figure 3 shows the data conceptual model related to a flat, and Figure 4 the functional hierarchy.

It should be noted that this approach breaks off the common practice of pre-defined chaining of design tasks. A detailed presentation of the ABS system is available in [9].

4.2 Object oriented approach and CAD data modelling : the example of ROSALIE

Among the various problems linked to the design of CAD data bases, one concerns the elaboration of relevant data models, able, in particular :

- to represent dynamical object structures ;
- to express the complete semantic knowledge ;
- to guarantee data coherency ;
- to manage partially defined objects ;
- to propagate constraints.

Classical data models (hierarchical or relational) have proved to be unsuited, but object oriented representation methods can answer these requirements to a great extent.

The CSTB has had the opportunity to develop some building applications with a system, named ROSALIE, that gives an aid to the elaboration of data conceptual models. Born in the CERT (Centre d'Etudes et de Recherches de Toulouse), then developed by the CAOMIP (a consultant group), this tool allows to structure data and to simulate the system operating.

Structures are based on an Entity-Relationship formalism, improved by functionalities peculiar to object oriented approaches. Concepts of class, relation, specialization and property inheritance can be found in ROSALIE.

The main characteristic of ROSALIE is to offer integrity control and constraint propagation mechanisms, for classes and relations. Concerning classes, each property can receive a functional constraint that allows to compute its value from other property values (constraint propagation), whereas relational constraints can be fixed between a set of properties (integrity control).

Figure 5 gives a partial view of the data structure defined for a thermal application. This structure contains not only data, but also procedures (attached to objects), whose upper level consists in computing the heat losses and the heating needs of a given flat.

Let us give an example of the use of the above mentioned mechanisms. The volumic heating needs (expressed by the B-coefficient) depends, among other parameters, on the solar transmission factor of the glass-wall common to all the windows ; this solar transmission factor depends, itself, on several glass-wall properties (glazing-type, frame-type, etc.). Besides, if the B-coefficient goes beyond the maximum regulation value, a warning messsage is displayed.

This application, even restricted, shows some interesting possibilities of the object oriented representation methods, due to the gathering of descriptive and procedural data inside the same entities. So, it is possible to build data models, highly structured, but yet evolving (since modular), that integrate some dynamical knowledge encoded outside the models in classical approaches.

5. Conclusion

More and more building professionals participating to research work (groups of architects, computing departments of construction firms, ...) take an interest, today, in the facilities offered by object oriented representation methods.

Some of these works have been carried out in collaboration with experts in computing science (university laboratories, software companies, ...), but most of them have not yet gone beyond prototype phase. It may be expected, however, that some other more ambitious projects could lead to professional products in a near future.

The CSTB, by developing some applications with advanced computerized tools designed in research laboratories, has shown that the object oriented approach (associated, or not, to expert system techniques) can contribute to the elaboration of softwares allowing to improve building tasks, especially during the design process.

REFERENCES

[1] CHOLVY L. "Structuration et intégrité des informations dans les bases de données en CAO. Définition d'un modèle et réalisation d'une maquette". Thesis report, ENSAE, December 1983

[2] BAILLY C., CHALLINE J-F., GLOESS P-Y. "Les langages orientés objets". CEPADUES, 1987

[3] "TECTON : un système co-expert de CAO intégrant le savoir architectural". Intermediary report, GAMSAU, November 1986

[4] AUTRAN J. "CAO et gestion d'informations. Vues d'objets en CAO. Illustration dans le domaine de l'architecture". Communication MICAD88, Paris, 21-25 March 1988

[5] GUENA F., LEININGER J-P., ZREIK K. and al. "X2A : pour un système de conception assistée par ordinateur en avant-projet sommaire de bâtiment" Final research report, CIMA, June 1986

[6] "Spécifications du système Krépis". Intermediary research report, CAOMIP, June 1987

[7] DAMIEN J-M. " PENELOPE : la planification de chantiers de construction". Magazine INTELLIGENCE ARTIFICIELLE, COGNITECH, 1986

[8] BOURDEAU M. "Artificial Intelligence and Building CAD : example in handling structured objects by an expert system to simulate design tasks". European Conference on Architecture, Munich, 6-10 April 1987

[9] DELCAMBRE B., MONTALBAN M. "Systèmes experts de conception basés sur les spécifications". Communication MICAD88, Paris, March 1988

PROJECT

FLAT
- MIDDLE-STOREY-FLAT
- UPPER-STOREY-FLAT
- OTHER-FLAT

EXTERNAL-WALL
- EXTERNAL-VERTICAL-WALL
- EXTERNAL-FLOOR

INTERNAL-WALL
- BEARING-PARTITION
- LIGHTWEIGHT-PARTITION
- INTERNAL-FLOOR

BLIND-WALL

LAYER

attribute name	attribute type	attribute value
1. thickness	list of reals	( )
2. conductivity	interval of reals	(0.025 2.)
3. resistance	method	-

FRAME	INSULATING-MATERIAL
1. ( )	1. (0.06 0.08)
2. (1. 2.)	2. (0.025 0.060)
3. -	3. -

WINDOW

GLASS-WALL

FRONT-DOOR

VENTILATION

JUNCTION-OF-TWO-EXTERNAL-WALLS
- JUNCTION-OF-WALLS-WITH-INTERNAL-INSULATIONS
- JUNCTION-OF-WALLS-WITH-EXTERNAL-INSULATIONS
- JUNCTION-OF-WALLS-WITH-UNLIKE-INSULATIONS

JUNCTION-OF-INTERNAL-WALL-AND-EXTERNAL-WALL
- JUNCTION-OF-INTERNAL-WALL-AND-EXTERNAL-WALL-WITH-INTERNAL-INSULATION
- JUNCTION-OF-INTERNAL-WALL-AND-EXTERNAL-WALL-WITH-EXTERNAL-INSULATION

JUNCTION-OF-EXTERNAL-WALL-AND-WINDOW-FRAME
- JUNCTION-IN-INSULATION-PLANE
- JUNCTION-OUT-OF-INSULATION-PLANE
  - JUNCTION-WITH-INSULATED-RETURN
  - JUNCTION-WITHOUT-INSULATED-RETURN

Figure 1 : Categories and prototypes for the thermal application developed with SMECI

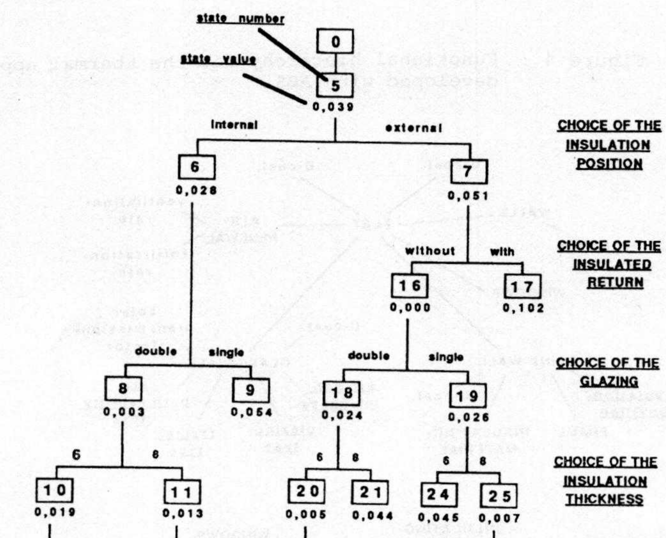
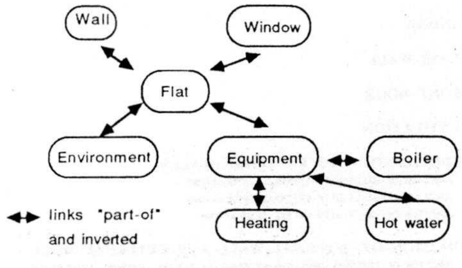


Figure 2 : Example of state tree for the thermal application developed with SMECI



Relations between categories

Properties	Default-values	Permitted-values
flat-inverted	-	-
glazing-type	single	(single, double)
position	exterior	(exterior, interior)
closing	not-good	(good, not-good)
air-permeability-class	AO	(A0, A1, A2, A3)
frame-type	metallic	(wooden, metallic)
area	-	[ ]

Simplified description of the WINDOW category

Figure 3 : Data structure for the thermal application developed with ABS

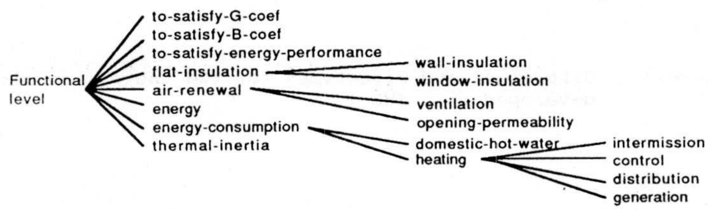


Figure 4 : Functional hierarchy for the thermal application developed with ABS

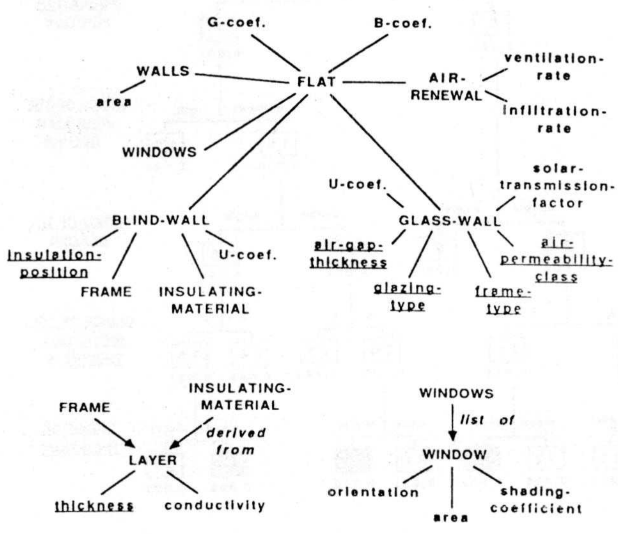


Figure 5 : Partial view of the data structure for the thermal application developed with ROSALIE