A COMMON DATA MODEL FOR COMPUTER INTEGRATED BUILDING

Luc BOURDEAU, Anne-Marie DUBOIS, Patrice POYET

Centre Scientifique et Technique du Bâtiment
BP 141 - 06561 Valbonne Cedex FRANCE.
Tel. +(33) 93 65 34 00
FAX +(33) 93 65 29 37

Abstract

The connection of various building performance evaluation tools in a collaborative way is an essential request to develop true CAD systems. It is a basic requirement for the future of integrated information systems for building projects, where the data concerning the multiple aspects can be exchanged during the different design steps.

This paper deals with the on-going research concerning the generation of a common data model in the framework of a European collaborative action, the COMBINE Project , which is supported by the CEC, General Directorate XII for Research Science and Development, within the JOULE programme.

The first step of the research concerns the progressive construction of a conceptual model and the paper focuses on the development of this Integrated Data Model (IDM).

The paper reports on the definition of the architecture of the IDM. The main issues and the methodology of the IDM development are presented.

The IDM development methodology is based on successive steps dealing with the identification of the data and context which are considered by the Design Tool Prototypes (DTP) to be connected through the IDM, the conceptual integration of this knowledge, and the implementation of the model on an appropriate software environment.

1. INTRODUCTION

Just like many other industrial sectors, the building industry expects major enhancements and productivity gains from the current computerization wave. This field takes today a rather significant part in the market of software tools such as CAD systems or evaluation softwares. However all these systems are characterized, when looking at them on a global point of view, by a deep diversity resulting from various data modelling, various problem approaches, various objectives,... This lack of homogeneity, expecially in the way of modelling this complex product that a building is, leads of course to productivity losses that an integrated approach could make possible to avoid.

Several researches and developments are going dealing with this integration problem. CSTB has been working on it for several years [1,2]. Some international approaches have also being launched. In that respect, the COMBINE Project, initiated by the CEC DG XII, is an exemple of a coordinated effort to propose on a short term basis an integrated design system prototype.

This paper aims at presenting the status of one of the main aspects of the COMBINE Project, which is the development of an integrated data model to serve as the basis of a data integration approach and which CSTB is strongly involved in on both conceptual and implementation levels.

2. THE NEED OF A COMMON DATA MODEL

A main difficulty to ease communication in the building industry is the variety of people who are concerned and the diversity of their views. A building construction project is the result of a complex process which implies many various skills, expertises and know-how and the work of many different branches of the building industry. Another difficulty is the variety of types of information which are to be exchanged by these numerous actors from simple messages to complex sets of data, drawings or values and even process elements linked to design, construction, maintenance,...

Today two approaches are being followed to meet these communication requirements. One of them consists in standardizing the form of the pieces of information exchanged between firms. This can be applied to information with a rather low semantic content (mainly for commercial purposes) and is based on messages which follow syntactical and grammatical rules defined through the Electronic Data Interchange (EDI) movement. ISO standards have been issued in this field and several demonstration operations carried out.

A second approach, which forms the subject of several basic research activities in the world, underlines the need of a powerful data model which would serve as a starting point for the development of sophisticated technical software tools. The main idea is to make this data model play the role of a central core to be used as a 'pivot' by various application tools introducing all kinds of information (graphical, topological, numerical,...). This common data model should also be able to ensure the coherence of the contained information, provide multi-purpose abilities, and even take account of process-oriented problems (conflicts, negociations,...) between the building actors throughout the life-cycle of the project.

Artificial intelligence techniques today appear to be able to provide researchers with appropriate tools allowing them to develop such an intelligent integrated approach [3,4,5]. As a matter of fact, these techniques propose very powerful data reprentation facilities (especially through object-based models) to support a common data model as defined above ; they also offer facilities to support reasoning mechanism representations.

As regards the common data model, it is supported to handle the objects of a given product together with their relationships in order to bear efficiently the information needed by the various actors in the various work domains.

3. THE PROJECT COMBINE

3.1. Goals of the project

COMBINE (Computer Models for the Building INdustry in Europe) [6] is a European collaborative action in computer-based building evaluation, which aims at a greater coherence in this field. It is an initiative within the JOULE programme of the CEC Directorate-General XII for Research Science and Development.

COMBINE will take a first step towards future intelligent integrated building design systems (IIBDS). The general objective of the project is to improve communications between actors in the design phase of a building by enabling a multi-criterion approach through the integration of several specific disciplinary tools at the disposal of the design team. Within its JOULE context the emphasis will be put on energy performance aspects and the use of Building Performance Evaluation (BPE) tools, which range today from simulation tools (with powerful analysis capabilities but poor evaluation support) to design-oriented calculation tools (with often good evaluation support in a given design context but limited analytical power).

The project started in mid-1990. The present phase is scheduled to end in the Autumn of 1992. Fifteen groups from eight European countries are participating in the project, which is coordinated by F. Augenbroe [7] from the Delft University of Technology.

The first phase concentrates on the automatic exchange of data among a suite of BPE tools. A number of software prototypes made of integrated tools adapted to specific design tasks will be developed. These Design Tool Prototypes (DTP) will be build upon existing as well as new BPE tools. The integration approach will be focused on data integration through the development of a common conceptual data model. This Integrated Data Model (IDM) will allow data exchanges to take place between the DTPs. The coupling of several DTPs through the IDM will constitute the IIBDS prototype that is foreseen as a main deliverable of the first phase of the project COMBINE.

3.2. The Design Tool Prototypes

The DTPs under development will be supposed to help the designers on different aspects of the design process in the energy performance domain. These aspects are connected to the construction design of external building elements, the design of the heating, ventilating and air conditioning system, the dimensioning and functional organization of inner spaces, the analysis of solutions through the use of a calculation tool in the early design stage and of a simulation tool in the late design stage, the energy-economic approach, and the shape definition of the building through a geometric modeller.

If the global architecture of the IIBDS prototype (figure 1) aims at supporting data exchange among the coupled set of DTPs through the IDM concept, the 'local intelligence' support to the use of the BPE tools will be provided mainly through the mapping between the IDM and the local aspect models.

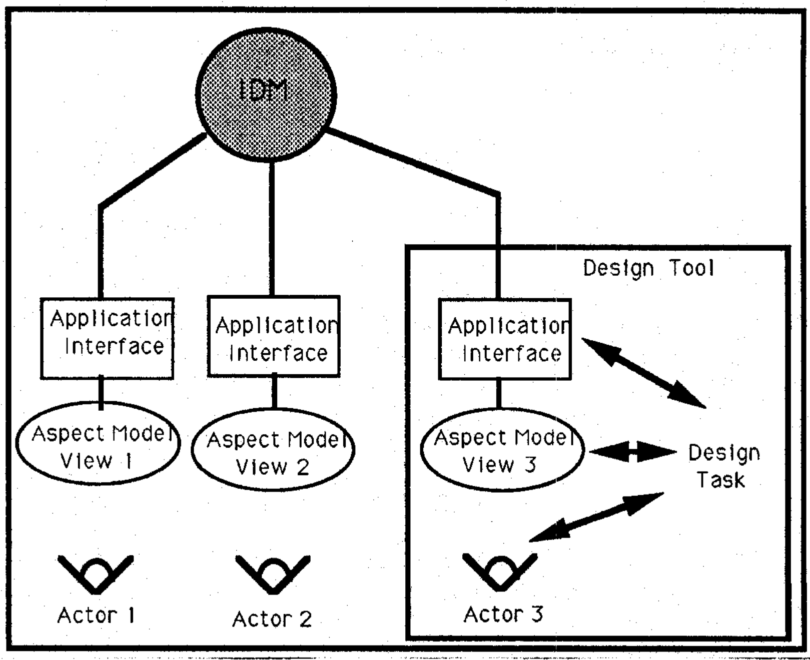

Figure 1 : COMBINE prototype architecture

4. THE COMBINE INTEGRATED DATA MODEL

4.1. A model for data integration

The various actors of a building project manipulate huge sets lot of data. These data are generated at a certain stage of the process, for example during the early design, updated one or several times, communicated between the actors,... One of the keys for easing data manipulating is data integration through a data model which, conceptually speaking, can be regarded as the central core to which all clients relate and with which they exchange their data. No direct link should exist between clients, other than through this central data model.

One of the main tasks in the COMBINE effort will deal with the development of such a common IDM, through which multiple building representations pertaining to the different DTP views will be exchanged. This building data model should therefore comprise all the informations which are needed for a sufficiently exhaustive representation of the building in the different stages of the project. Hence it should permit the insertion and the extraction of all kinds of different views of the building from the various actors or the diverse aspects. The effort will essentially be focused on the design life-cycle phase of domestic or non domestic buildings, with a multi-criterion design support objective, and with a special attention to energy efficient aspects.

4.2. The IDM architecture

4.2.1. Adherence to the STEP standards

The IDM on-going effort takes advantage of the current progress of the development of the ISO-STEP standard which supplies a general framework to harmonize ongoing data modelling works. According to the STEP philosophy [8], the IDM through which the exchange will take place is specified in two levels : a conceptual level and a physical level.

At the conceptual level, STEP introduces a conceptual schema containing a set of entities and the relations between these entities. Different layers are considered at this level, which enable :

- a shape presentation layer, with all data aspects of the shape of the product and how the shape is presented,
- a definition layer, with all data aspects of the product which are not shape related; this layer contains three sub-layers dealing with context definition, product definition and property definition.

At the physical level, STEP introduces :

- a standardized schema definition format EXPRESS, which is a powerful tool for concise and complete data definition,
- a standardized neutral exchange file format; this so-called STEP-file contains a header part (the EXPRESS data schema) followed by the data part, containing the instantiated entities which describe the actual product.

The STEP conceptual framework provides guidelines to the modelling effort, but with respect to the AEC model, it should reach a more stable and comprehensive form to represent as such a definite schema to which the COMBINE development should stick. Considering the physical level, the EXPRESS language and the ISO neutral file format represent useful tools to exchange the data model content. Of course, the internal representation of the IDM is not directly built upon EXPRESS, and relies on very powerful tools, handling directly a rich semantic data model, taking advantage of the most recent progresses in knowledge based modelling and associated representation techniques. Once requests are sent to the IDM, so as to extract the relevant set of entities for any DTP use, the appropriate content corresponding to the objects to be exported is then translated into both EXPRESS files (i.e. for the conceptual schema) and ISO STEP neutral files (i.e. for the bulk of instances to be exchanged).

4.2.2. Some main issues of the IDM development

A number of main issues are raised when the development of such an IDM for building design is initiated. Several of these issues are today under investigation in the framework of the COMBINE IDM task in order to be able to propose a pertinent example of a common data model for computer integrated building at the end of the first phase of the project.

The IDM development for the expected IIBDS prototype raises for instance the following considerations.

The buiding design process does not entirely fall within the logic of industrial construction. For example - and these two aspects are also encountered in the large ship building field (i) - a great amount of actors with their own vocabulary take part in a project and (ii) - each building is unique and requires to take into account its specificities.

In order to define the exact content of the central data model, it is needed to precise the intended scope of the IDM. As a matter of fact it is not possible to envisage that the central data model can contain the fully exhaustive set of all the data used in all the BPE tools embedded in the DTPs of the prototype. A large number of these data are not relevant for communication needs because they are just useful for a specific point of a design aspect without any link to and consequence for other aspects, or even because they are only considered in one of the BPE tools. Therefore, it is necessary to analyse deeply the design process and the full list of data in order to make a clear distinction between these data which need to be exchanged through the central model and those which are considered to be application-specific and thus 'private' to a given DTP.

Among the various top-down concepts and abstraction mechanisms which can be considered in a conceptual approach, it must be chosen those which are relevant to be supported by the IDM for getting a pertinent IIBDS prototype. A general agreement among the IDM group lead to recognize the usefulness of a set of abstraction mechanisms, which on the other hand may be implemented using many different programming paradigms with a wide range of computerized systems. The following concepts, among many others being considered, are worth being mentionned :

- Generalization-specialization: in order to reduce data redundancy it is needed a mechanism to consider entities at different levels of specialization such as a hierarchy based on the generic, specific and occurence concepts (for example, in order to allow the model to consider easily an airduct, a 0.15m-wide PVC airduct, a 0.15m-wide 6m-long PVC airduct placed between A and B).
- Characterization: the entity description should support relationships such as 'aspect-of', thus enabling an aspect-oriented view of the product (for example concerning color, strength, cost).

- Decomposition-composition: the data model should support relationships such as 'is part of', thus enabling views on different levels of aggregation.
- Life-cycle stages: an complete data model should consider all the building life-cycle stages, that could be classified according to some process-oriented categorizing of specific decision reference points. As integration across life-cycle stages is one of the prime targets of integration, the data model should support these life-cycle views and their relations.

The IDM which is foreseen to be available at the end of the first phase of the project will of course be limited in its application domain. However it is expected that a complete data model could be developed in the coming years. Thus future extension possibilities of the produced IDM must always be kept in mind and the support of the above mentioned concepts provides some guarantee of this possibilities.

As different application views imply different levels of abstraction, it is the utmost importance to support useful abstraction mechanisms. It is debatable whether characterization and decomposition supply enough richness in this respect. For example, an application-specific description and physical modelling approach will often derive a very particular abstraction.

At last, it appears that important operational and user aspects of the central data model, such as the ideas of data ownership, model version numbering, access authorization and so on, are generally missing from today attention of the data modellers. In fact, if it is wished that the data model could support the process along the life-cycle stage axis, this will entail a great deal of implied procedural knowledge concerning these aspects. Although rapid progress can be seen in CEC Computer Integrated Manufacturing projects, a large part of it deals with fairly simple part production processes and it is not clear at all how it can be applied profitably to the building industry which, as mentioned earlier, does not entirely falls within the logic of industrial construction.

These few reflections show how large the challenge appears when facing the development of complete building data models. Therefore it is not wise seeking for the actual development of a full-blown IIBDS in a short time. However the first phase of COMBINE should result in a IDM prototype which will serve as proof of the chosen concepts and be the first step to more sophisticated integration models.

4.3. The IDM development methodology

4.3.1. Introduction

In order to be able to develop the integrated data model for the various BPE tools and DTPs of the COMBINE IIBDS prototype, a progressive modelling approach has been chosen. This approach makes a clear destinction between the conceptual modelling activity and the software implementation work.

On one side, the conceptual modelling activity, in a first step, must identify the BPE tool data and the DTP design contexts. Afterwards, an integration process strictly speaking provides, from the chosen abstraction mechanisms and the identified semantics of the domains, the set of entities and relations which will constitute the conceptual data model.

On another side, the software implementation work must define a suitable computer-based representation of the conceptual model.

4.3.2. Data and context identification

This task must provide the basic raw material for the definition of the content of the conceptual data model. It aims at providing a clear description of the DTPs input and output data through the development of a comprehensive data dictionary and NIAM diagrams [9] supporting the description of the relationships between data. This mandatory first step in the model development task enables to identify and to remove ambiguities, anomalies or even misunderstandings between the teams who provide the BPE tool and DTP data and the IDM data modellers.

4.3.3. Conceptual integration

The data dictionary is mainly useful to enable the IDM task to carry out some sort of semantical integration and to initiate the creation of a conceptual object base. Semantical integration looks for a perfect correspondence between a given term and a given concept for all BPE tools and DTPs. This means that harmonization must be reached on the lexicographical items and their associated meaning. This data dictionary and the associated NIAM diagrams lead to a set of entities sharing a common meaning across the clients and avoiding redundancy and misunderstanding among them. They enable to describe the structure and content of the entities and elucidates the relationships linking the concepts to each other.

One of the key aspects of the integration process is, as mentioned earlier, to identify the abstraction mechanisms which will permit to model all the concepts satisfactorily an to avoid any very specific models. This implies to define the common model through a 'top-down' approach introducing a set of generic concepts which will be the driving force of the integration process.

This methodology should lead to the description of the IDM conceptual data schema in the form of NIAM diagrams, a data dictionary, an object dictionary and a relation dictionary.

The conceptual data model can be built at two levels. A first level describes the classes of the 'real' objects (building, walls, windows, heating systems,...). A network of relationsbetween these classes and their instances expresses the semantics of the whole schema. The second level is a meta-level, which contains the definition of abstract classes that describe the behavior of the sub-classes (i.e. instances of the meta-classes). All the classes of the first level should be instances of the meta-level classes. Any modification at the meta-level will entail changes at the real level, thus adding modularity to the whole schema. This second level can be considered as the description of the methodological choices of the modelling approach. Some examples of envisaged meta-concepts are the following: system, component, staple (a generalization of the view concept), summary, design step.

An assumption adopted so far is that the differences between the design views will result in defining as many different relations between the objects but not different objects by themselves. So the number of different objects will be small, but the number of relations rather large. However, this implies to introduce different aspect models for a same element, such as a 'wall', which can be considered either with its surfaces and finishes or without. With this assumption it is possible to define a limited number of object classes to be considered as the basis of a common data schema. These classes can be gathered around some main entities such as building, space, enclosure-element, window, site, usage, technical systems, energy performance,...

4.3.4. The implemented IDM

The Integrated Data Model which will be delivered at the end of the first phase of COMBINE will also be implemented on a computer through an appropriate software environment. This environment must enable to achieve the representation of the concepts of the conceptual object base (set of abstraction mechanisms, set of objects with their contents and relationships), together with the management of the entities (including browsing, editing,...), the extraction of a subset of the overall data model content suitable for specific needs of a particular actor, the exportation of the data model as a set of Express entities and ISO neutral files.

Appropriate implementation facilities are required to translate the model in a computer interpretable form without any loss of semantics and to offer a software engineering environment taking avantage of the most recent techniques, leading to reusability, robustness, expendability,... Recent but already well recognized programming paradigms well suited to account for all these smart implementation properties, and moreover leading to a straightforward translation of the kind of material produced by the conceptual work, are for example frame-based representation techniques, object-oriented programming approaches, and of major interest, knowledge-based environments providing both facilities for the data representation and for the functional aspect of any conceptual modelling exercise. Data modelling diagrams and functional requirements are translated in a rich semantical model taking in charge the representation of the information (i.e. it may be frame-based or object-oriented or a mixture of both) and the process flow offering techniques to model the operating part of any application (i.e. tasks, rulebases, rules, daemons, constraints), thus providing a schema to express in an homogeneous manner the application knowledge.

The MIPS (Many Integrated Paradigm System) software, developed by CSTB, takes advantage of many of these approaches, and has been chosen as the basic implementation platform of the COMBINE project. The MIPS environment is a very efficient tool based on a reflective virtual reference object layer (currently mapped on a physical object-oriented language which is the Micro Ceyx module of the Le_Lisp System and soon TELOS a version of CLOS) and the object-oriented graphic interface toolbox AIDA. An overview of the MIPS system is available in [10] and a representative subset of its fundamental concepts is presented in another communication [11] to this seminar.

The work should also lead to an implemented software including the IDM and :
- ensuring the data exchange between the DTPs,
- opening the road to the integration of new DTPs,
- being a sound basis for an upper layer (Intelligent Integrated Building Design System)

5. CONCLUSION

If computerization of the building sector is today growing up, it obviously appears that a strong need of integrated functions is underlined in all the software environments proposed on the market and especially in the design sector. In this context a lot of research works are beginning to take place. The CEC COMBINE project can be mentioned in this field on the energy performance domain. With regard to integration aspects, the COMBINE project is expected to result, on one hand, in concepts on which the development of full intelligent integrated building design systems might be based, and on another hand, in deliverables such as a common data model for computer integrated building supporting several design functions and implemented in a suitable software environment, and a demonstration design tool showing how design tool prototypes can communicate through the implementation of actual data exchange.

6. REFERENCES

[1] A. M. Dubois. Prototyping approach of multi-actors computer aided design for buildings in the frame of the CIBAO project. *Proc. of MICAD 90*, Paris, (12-16 Feb. 1990).

[2] A. M. Dubois, P. Poyet, L. Laret, L. Bourdeau,. Knowledge Integration : The Next Step to Data Integration, *Building and Environment*, to be published (1991).

[3] P. Poyet, A. M. Dubois, B. Delcambre. Artificial Intelligence Software Engineering in Building Engineering. *Micro-computers in Civil Engineering*, An International Journal - Elsevier Science Publishers, Vol 5, n° 3, p. 167-205 (1990).

[4] P. Poyet, B. Delcambre. Impact of Information Technologies on the Design and Operation of Buildings. *Proc. of the European Network of Building Research Institute / CEC Seminar on Construction Research Needs*, 7 pp (October 31, 1990).

[5] P. Poyet, P. Haren. A.I. Modelling of Complex Systems, in: Modelling Techniques and Tools for Computer Evaluation, R. Puigjaner and D. Potier Editors, *Plenum Publishing Company*, London, p. 265-290, (1989).

[6] COMBINE Newsletter, Number 1, CEC DG XII, (June 1991)

[7] Augenbroe, G., Laret, L.. COMBINE Pilot Study, Report CEC DG XII, (1989).

[8] B. Björk and J. Wix. An Introduction to STEP, VTT and Wix McLelland, England, (1991).

[9] Nijssen and Vermeir. A Procedure to Define the Object Type Structure of a Conceptual Schema, *Information Systems*, Vol 7 no 4, (1982).

[10] P. Poyet. Integrated Access to Information Systems. *Applied Artificial Intelligence* - An International Journal, Hemisphere Publishers, Vol 4, n° 3, p. 179-238, (1990).

[11] E. Brisson, P. Debras and P. Poyet, A first Step towards an Intelligent Integrated Design System in the Building Field, *Proc. of CIB W78 seminar on Computer Integrated Future*, Eindhoven, (1991)