Building design with a multi-discipline CAD system using object-oriented environment.

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ABSTRACT :

The aim of our paper is to present a multi-discipline CAD system named CONCEPTOR which allows the user to work during the various stages of the building engineering design. Most of the actions are dedicated to the building performances assessment for various technical domains with an extension of tools towards:

- economical estimating,
- quality analysis,
- checking of the solutions according to the regulations, the standards and the constraints established by the designer,
- coherence of the various works and solutions.

During the design process we try to manage the consequences of a modification on the results of the previous calculations made by the user.

In order to carry out these actions we have chosen to use an object-oriented approach which made the management of the dynamic evolution of data easier.

We propose to develop:

- a definition of the objectives of the CAD system according to the needs of the designer.
- a definition of data structuration taking the various representations of the same object into account.
- an example of evaluation tools for the thermal component.
- techniques for data generation according to the needs of technical modules.
- the way we manage the multi-discipline design and the additional aspects (quality, coherence ...)

1 INTRODUCTION

At the beginning of the nineties we could consider the development of C.A.D. systems for building as being the result of various improvements :

- those related to the field of research in computer sciences: D.B.M.S., object-oriented languages, operating systems, graphic tools and graphic systems... Even though the developers of C.A.D. systems asked for more, they generally meet problems to choose between various available tools,
- those associated with the engineering area.As regards, building parts researchers had been producing more and more sophisticated models: anyone being well aware of the high level reached in building simulation,
- those resulting from users's needs: as the know-how of the developers was increasing, the demands of the users were growing more accurate and reaching a wider range.

Our work took place within this context and its objectives were to gather different results in order to produce a prototype of multi-discipline and multi-stage CAD system for buildings.

2 OBJECTIVES DEFINITION

When we propose an answer in terms of C.A.D. system one must consider the influence of various improvements of the development environment but one must also remember the specificities of the application area. Concerning our work we can consider the following as the basis of any development :

2.1 Multi-users aspects

There are at least three kinds of approaches :

- architectural view : in fact, the architectural design is made before the technical design. The architectural draft constitutes the entry point for the system. The general aim is to develop the project around this proposition by addition of all the technical views.
- engineering : this domain covers the technical design from the first choices associated with the architectural proposition to the execution drawings. Various engineers are working during this stage of design, consequently we have defined various fields of study : structure (concrete, steel, wood studied trough vertical and horizontal stability), foundation (shallow and deep), framework (steel, wood), acoustic (insulation and treatment) and different thermal calculations (further developped).
- economic appraisal : this is a very general domain which leads to a necessary connection between all the architectural or technical propositions. As a matter of fact, when it comes to decrease the construction cost every point of view has its importance.

2.2 Diversity of tools

In order to elaborate his own design, each user needs various kinds of tools particularly well suited to his field of work. But, despite the nature of the study we can find out a common way to implement the design process. We have identified the following kinds of treatment :

- elaboration of a proposition : this operation can be made through graphical or descriptive tools
- technical assessment : from the direct evaluation by simple calculations to very sophisticated methods for

performance analysis. This is the domain of the common algorithms of engineering studies.
- modification of propositions : every time the result of an analysis is not satisfactory it leads to a modification. To work in the field of aided design means that it is necessary to elaborate the tools which give to the user pieces of advice for a new proposition, the list of possible actions and indications about the consequencies of a modification.
- evolution of a proposition : when a group of propositions have been validated according to all the objectives, it is possible to go on with more details for each technical view.
- tests of variants : using the possibilities of fast evaluations, it would be interesting to test various solutions. Furthermore, in order to do so with a CAD system, the tools are the same as for modifications studies.

2.3 Multi stage design

To obtain the final solution for the project it is necessary to follow a process including different stages more or less identified as statutory (in France: building permit, preliminary schematic design, detailed design). These steps impose the comparison of the different propositions but on the other hand lead to a stability for one level. For instance, we know it is possible to develop the detailed design for one technique only when a global agreement on the previous stage is obtained. Thus, the designer can go on with its design being sure that the result will remain in an acceptable field. In terms of data processing this feature of the system implies the management of conflicts and helpful tools for a coordinated evolution of the project.

Whatever the domain we have identified three main stages :

stage 1 : it corresponds to the main choices and orientations for the technical design

stage 2 : giving rough measurements for the works until they globally satisfy the regulations

stage 3 : detailed design and optimization. At the end of this stage, the execution drawings could be obtained.

It's worth noting that these levels represent a reference as to the state of the designing process but are in no way a clear-cut barrier between two kinds of calculations. As a matter of fact, within one stage different kinds of tools can be found out but all these modules lead more or less accuracely to the same aim .

2.4 Tools for aided design

The third stage is chiefly the domain of the algorithms. During the previous stages, as the users made their main decision they needed piece of advice in order to make their propositions coherent with the others. The tools we can elaborate for this kind of help allow to realize:
- the integration of expert's knowledge in order to give pieces of advice for orientation choices.
- the use of simplified or adapted calculations in order to evaluate the consequences of decisions. As a matter of fact, because the level of needed data, the common modules for simulation are often only available for the last stage.

2.5 Multi-discipline management

The simple gathering of different techniques doesn't involve coordinating work. As was previously stated it is basically compulsory to manage the concept of stages and to share data and knowledge. We believe that in addition to this basic treatments at least should be introduce two functions :
- coherence checking : in order to constantly evaluate if the various propositions are valid in terms of technological feasibility or regulations. This checking can also be extended to the verification of constraints initially choosen by the designers,
- quality : improvement of the quality by increasing the values of assessment criteria which represent objectives satisfaction. Steering the evolution of the project is made by design problems diagnosis.

Both fields are typically multidisciplinary because they lead to consider the interferences between different propositions made by the various designers.

2.6 Data generation

The models used for building simulation often need a lot of input data mainly due to the level of detail in which they can be useful. Besides, these data generally don't correspond to the decision variables which are the most interesting to handle for the users. Therefore it seems that a good solution would consist in deducing the needed input data for the simulation modules from the available data (decision variables and other data representing the state of the project).

The prototype CONCEPTOR has the ambition to try to give an answer through its composition and its organization taking in account the above-mentionned preoccupations.

3 GENERAL ORGANISATION AND DATA STRUCTURATION

3.1. General organisation

Associated to the multi-disciplinary view of the design process we have identified various functions separated in two groups : the functions of the technical approaches and the functions of the multi-disciplinary ones. As we can see in table 1 most of these functions are split according to the various stages. This is not true for the quality and coherence modules which have the same purpose all along the designing process, even though their activation depends on the nature of available data at the time it occurs.

3.2. Data structuration

For the development of CONCEPTOR we chose to use an object-oriented representation (O.O.R.). This is the result of previous studies (L.G.C.H.et al. 1989 ; Dufau et al. 1990) that have shown the necessity of making the greatest effort in data structuration and trying to integrate all we can attach to an object as soon as possible .

In fact, data structuration using O.O.R. is particularly adapted to solve most of the problems of the multi-disciplinary process. Detailled explanations to follow.

Figure 2 simply presents the skeleton of data organisation.

TECHNICAL VIEW

1.Structure component

stage 1 :	- choice of the type of structure (for walls, façades, floors ...)
stage 2 :	- technological definition of each work (beam, post, wall, slab ...) - rough dimensions for each component study of stability
stage 3 :	- detailed dimensions for each component according to the regulations - detailed study of each work

2.Foundation component

stage 1 :	- choice of the system (deep or shallow)
stage 2 :	- rough dimensions for each part (strip footing, raft foundation ...)
stage 3 :	- study of "portance" and settlement calculation of each work as concrete work

3.Thermal component

stage 1 :	- choice of kind and thickness of insulation - choice of energy and kind of thermal conditioning
stage 2 :	- statutory calculations (GV and BV coefficients) - evaluation of thermal loads - first calculations for equipments (design of heaters, consumptions)
stage 3 :	- dynamic simulation - study of comfort and detailed consumptions (C coefficient) - detailed calculation for equipments (optimization of performances)

MULTI-DISCIPLINARY VIEW

1.Economic assessment

stage 1 :	rough evaluation using global unities (flat, set of rooms ...)
stage 2 :	evaluation by ratios (per square meter of works ...)
stage 3 :	detailed evaluation using all the details for each work

2.Quality : improvement of the values of assessment criteria

3.Coherence / feasability : checking of solutions in terms of technology availability

Fig 1 : The functions of CONCEPTOR and summary decomposition according to the different stages

4 EVALUATION TOOLS : THE CASE OF THERMAL COMPONENT

The objectives of engineering is to complete the architectural drafts making technical choices and to valid the different proposals. Its application field is very large and among all the technical functions, thermal component is one of the most important for a good performance of the designed building. So, we chose the thermal component to describe the kind of evaluation tools we can use in a C.A.D. system to reach the aims of each level in multi-stage design. The following table (fig. 3) gives the organisation of the thermal component we have adopted in CONCEPTOR, knowing that the starting point is the architectural sketch. The orientation, the environment, the dimensions and the compacity of the building are then defined. Some detailed information corresponds to the french context which is the only one considered in CONCEPTOR at the present time .

At each stage of the designing process the proposal must be stabilized to be sure that a more detailed design of the next stage can be undertaken on a reliable basis : this result is obtained by using the loop "'proposition - assessment - modification" at the same level of definition, as ofen as necessary until stability of decision is achieved This characteristic is to be found in all the technical fields. For example, to verify thermal regulations at stage two, we need not only the thickness of insulation layers but also the entire composition of the walls which is defined in other different technical fields at previous or even at the same stage.

Moreover, the stability of the decision is required independently from evaluation tools. So the diversity of the potential tools is preserved and, at each stage, the new results are always reliable when they are incorporated in the common data shared between all the functions. It is obvious that some evaluation tools are better adapted than others to satisfy the above conditions which are essential to the general coherence of a C.A.D. situation. The many thermal evaluation tools available are unfortunately not really suited to a multi-discipline C.A.D. system as CONCEPTOR. They often correspond to complete procedure of thermal calculations whereas what is required is knowledge fragments associated to thermal objects. Besides, this "cut out" of the thermal models is necessary with O.O.R. data structuration to identify elementary functions and corresponding basic formulations which can be linked to specific objects related to the thermal component.

The "proforma" concept (Sornet 1986) which is a standardized information form concerning available and future thermal models makes their fragmentation into elementary functions easier. The generalization of this concept to complete evaluation tools in other technical fields would be very useful. We have to point out that some complete thermal models could be used at stage three (detailed simulation models) or even two ("GV" or "BV" statutory calculations). Therefore linking these entire programs with C.A.D. systems such as CONCEPTOR is a problem at the present time because, in the software organisation, the calculation part is never disconnected from the other parts. Nevertheless, it is always better with O.O.R. data structuration as that used in CONCEPTOR (Bull 89) to associate knowledge fragments to objects with "reflex" or "methods". So, each object or class of objects contains in an intrinsic way the elements which lead to its own structural modification according to the value of their attributes and the results of assigned treatments .

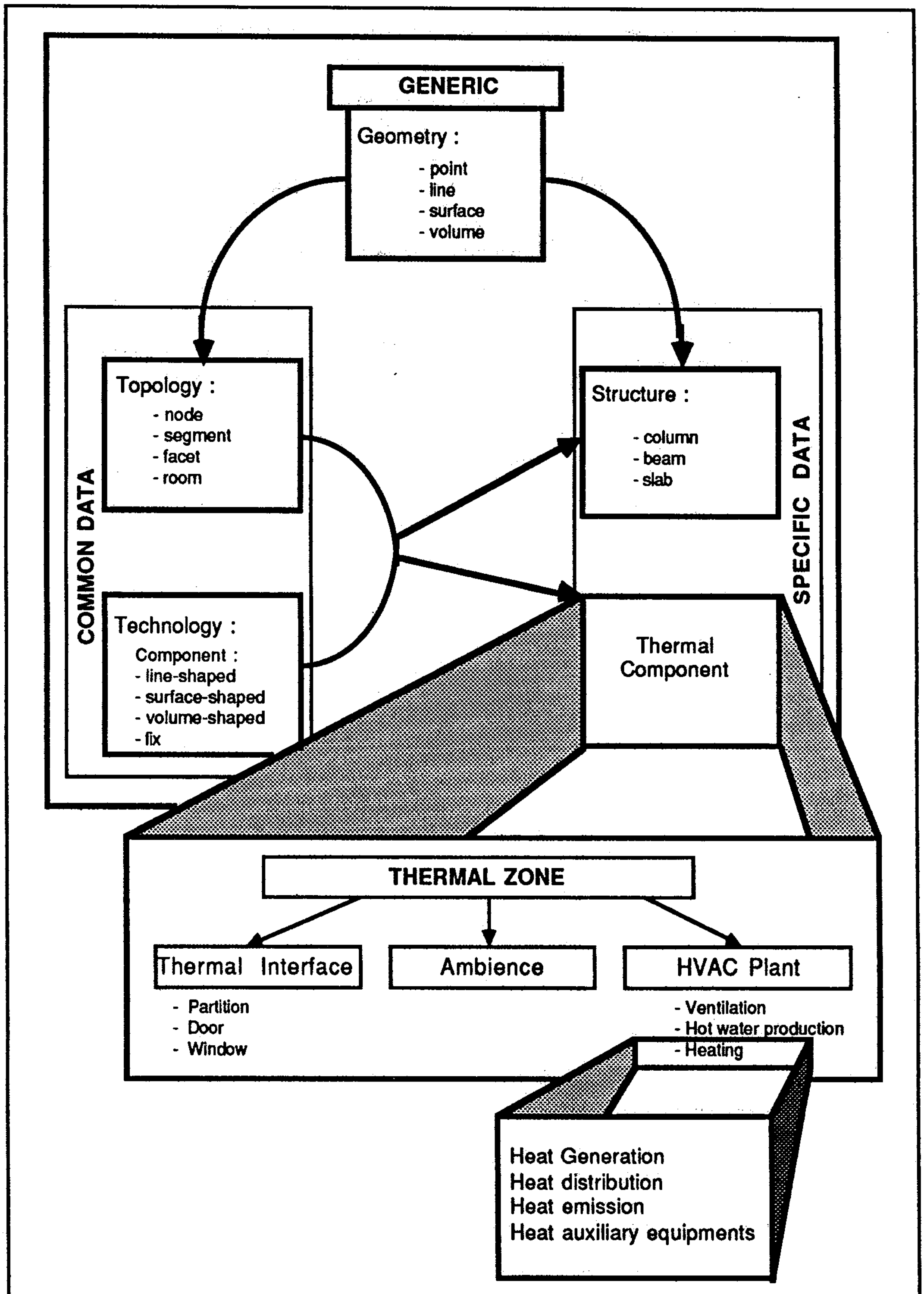

Fig 2 : Conceptual Schema

For instance, when the object "thermal wall" is created, it has some geometric attributes derived from the general data base (orientation and coordinates of the facet to which it is connected). This situation corresponds to the architectural sketch which is the starting point of the design adopted in CONCEPTOR.

At the end of stage one we know :

- the area of this wall by deducing the possible window area of the facet area

Stage	Objectives	kind of evaluation tools
Stage 1 : choice of technical decisions	Envelope of building - dimensions of glazed surface - position and thickness of insulation layer - thermal capacity allocation	ratio method and expert rules
	Thermal conditioning plant - choice of energy - choice of HVAC system - choice of hot water production sytem	expert rules
Stage 2 : Confirmation of previous choices and primary design of thermal equipments	Envelope of building - estimation of "G.V." and "B.V." coefficients [C.S.T.B.1989] (to valid the previous proposal) - verification of thermal regulations (only for "G.V." and "B.V. coefficients) - thermal loads evaluation	approximate calculations statutory calculations simplified method
	Thermal conditioning plant - power of heat (or cold) generation plant - design of heaters - estimation of energy consumptions - choice of thermal regulation	approximate calculations "degree-days" method with average efficiency of the thermal equipments expert rules
Stage 3 : detailed design of thermal equipments and performance evaluation	Thermal conditioning plant - design of all the thermal equipments and auxiliaries - design of water pipe (or air) networks - thermal and hydraulic (or aeraulic) balance of the networks - energy consumptions	specific methods specific methods iterative balance method refined "C" method (statutory calculation)
	Thermal performance - dynamic behaviour of the building * influence of intermittent working of thermal plant * influence of under designed plant * evaluation of overheating risks - thermal comfort study - optimization of thermal performance and optimal management of thermal plants	Simulation models of reduced order (from single order "R.C." model to more or less detailed model) simulation model with specific calculation for the evaluation of thermal comfort adapted simulation model

FIG 3 : ORGANISATION OF THE THERMAL COMPONENT

- the position and the thickness of the insulation layer of this wall by the application of the " D GV method" which is a kind of ratio method
- the entire composition of this wall thanks to other technical fields such as "Structure" and Acoustics"

During stage two, users can slightly modify the previous composition if the requirements in accordance with the thermal regulations are not well satisfied by the proposal at the end of stage one.

Stage three allows valuation of other attributes to this "thermal wall" as energy storage, accessibility to the thermal capacity (Laret 1980) and other dynamic characteristics (response factors, eigen values and eigen functions (Berges 1986)) useful for working on detailed simulation models (convolutive models (Roldan 1985) or modal models (Mokhtari 1988)). These characteristics are valued by "methods" which are specific basic formulations linked to the class of the object "thermal wall".

The O.O.R. data structuration is well adapted to this cycle of successive changes to realize an evolutive design of buildings. So far, using CONCEPTOR, we have carried out the part related to the thermal envelope and demonstrated the feasibility of this kind of approach.

5 TECHNIQUES FOR DATA GENERATION

One of the main interest of the C.A.D. systems is that they contain a great part of information required for all technical modules. Consequently, using a C.A.D. system leads to suppress the part of initialisation of data but introduces a phase of data generation, as automatic as possible.

In a C.A.D. system, a set of objects modelises the building. Every conceptor can have access to and share this common and physical description.

Each technical modules uses a specific model, usually different from the general model, but it corresponds to :

- an external view of the common data, directly readable in the data base of the C.A.D. system, such as the nature and thickness of the insulator. In this case, it is not necessary to develop a specific software, the polymorphic aspect of the object allows access to common data with a technical view.
- a certain interpretation of the general model. Considering the different hypotheses in relation with the technical module, it is possible to propose a generator, a software that can build the technical model from the common data base, as complete and automatic as possible. The generation method must be in accordance with the design level. Indeed, it enables to generate a technical model according to the definition of the project and the expertise of the designer.At the most detailed level, almost all the information needed by the generator is available, then an algorithmic procedure is generally enough to deduce the technical model. On the contrary, at the first stage of the designing process, the generator must fill the lack of information by using different techniques. It consists more in building a technical model than in deducing this one. Two techniques we can consider for the generator are :
  - using expert rules representative of the know-how of the thermal engineer.
  - some method based on a range of samples.

The interests of this data generation are obvious, notably :

- the part of initialisation of data for the technical modules disappears,
- in terms of design :
  - Each technical user can be sure that the data he uses are coherent with the project. Indeed, the technical model could be considered as a specific and virtual view.
  - The guarantee of using a calculation model, compatible with the designing stage. In fact, the generator only gives a result if the definition of the project contains all the necessary information.

The connection of technical modules to C.A.D. system introduces some new constraints, consisting in the feed-back of the results of the simulation to the common data The consequences of the simulation must be integrated to the common information in the C.A.D. system. Then, some specific part of the technical modules have to be developed to this purpose.

In CONCEPTOR, for example, the generator for thermal modules runs as follows:

- The thermal engineer defines a thermal zone by pointing to the concerned rooms.
- The generator deduces the geometry of the zone : volume, surface,form...
- It recognizes thermal walls.
- It searches for the thermal bridge in accordance with the level of design, either real, if information is sufficient or using ratio.
- It lists the thermal equipment.
- It builds a model, adapted to the various thermal tools.

6 MANAGEMENT OF THE MULTI DISCIPLINE DESIGN

The multi-discipline design involves sharing the various tasks performed by the members of the design team. Each of them develops his own view of the project, which results from the treated technical problems.

These different views of the project entail a parcelling of the information. The C.A.D. system must be able to manage this information and to guarantee its coherence.

CONCEPTOR fulfils this function through two aspects :

- structuration of information and its conceptual organization,
- existence of specific multi-technical units intended to check the technical coherence and feasibility of the project and to evaluate and improve its global quality.

6.1 Structuration of information

The organization of information, its distribution and the way the different technical components can have access to it, constitute an essential part of the way the considered problem can be solved.

The above-mentioned figure (fig. 2) shows that it is organised into three main parts :

- a generical one, which describes the geometric information,
- a common part for all the designers, which describes the shape and the technology of the building,
- a specialized one, decomposed into as many sub-schemes as there are technical components.

The conceptual scheme is implemented through an object oriented representation which allows to take in account a lot of additional aspects, which are not easily implemented with a traditional environment:

- the procedural part, attached to each object, by means of messages and deamons expressed by the way of algorithmic or expert rules. A self controlled behaviour can then be associated to each object.
- the encapsulation, which allows to have access to the information included in the objects, regardless of their physical representation.
- the inheritance, to define a class of objects by specialisation or restriction of an another class.

These two latter aspects improve the possibility of maintenance and reusability.

The partition of the scheme in accordance with the specificity of each technique, as described above, do not entirely satisfy the idea of a multi-technical view. As a matter of fact, a number of objects, common to all designers are not felt and manipulated in the same manner by each of them.

This polymorphous aspect of the objects is randered by the way they react to the user's request. For example, an object of the class "reinforced concrete beam", looked of by a thermal designer, will not give information about its reinforcement, a kind of information that is not used by this user. Conversely, the system will forbid the modification of the thickness of insulation wall by the structural designer.

6.2 Specifical multitechnical units :

The multitechnical design aspect is also randered by the continiuous control of the feasibility and coherence of the technical project through transverse module.

This unit works in the background and tells the designer about actions or choices which are in conflict with the rule of thumb or the choices of the other users.

Another unit evaluates the global quality of the project. It also proposes some suggestions to improve the quality of the design. In order to do so, it proceeds by identifying prototypes (Lefebvre 1991).

7 THE REALIZATION

The above described fonctionalities of CONCEPTOR show that it is necessary to have:

- a development language, which associates the most recent formalisms in terms of programation and knowledge representations : functional programing, classes, methods, deamons, predicate calculations and production rules. Furthermore, such a hybrid language will have to :
  - . have some fonctionalities in terms of object persistence,
  - . allow a dynamic evolution of the structure of the object,
  - . be able to define and manipulate 3 D graphics entities.
- a knowledge base with:
  - . a library of :
    - . geometrical functions compatible with the conceptual scheme,
    - . technical functions (structure, thermal, ...) in which we take the methods describing the class behaviour,
  - . a base describing the non algorithmic part of the behaviour of the objects.

The study of the existing products have shown:

- the unavailability of an hybrid language manipulating 3 D graphics objects,
- the absence of technical evaluation library,
- in return, the existence of many technical software which we cannot split into elementary functions.

These facts led us to make a prototype in two units :

- a graphics input unit, developed by addition of an object oriented overlayer to AUTOCAD (Autodesk 1989),
- the kernel of CONCEPTOR realized with the programing tool KOOL.(Bull 1989) This environnement of development gathers a functionnal programming language (Lisp), an object language and a rule based system.

At the present time, the prototype makes technical evaluations associated with structural and thermal components. The acoustic and foundation components will be developed.

8 CONCLUSION

Comparing the needs for building simulationists and CAD system developers we can say that it seems interesting for building simulationists to use CAD systems, at least because of the availability of the data describing the project. On the other hand, for CAD system developers, the need for specialized tools is rather oriented towards partial modules than towards multi-purpose softwares. It entails the necessity of splitting such a product after the definition of the objectives of each part. Being able to manage both aspects of building simulation and aided design is highly desirable if we hope to realize a suitable answer for integrated design.

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