A KBS FOR THE INTEGRATION OF ACOUSTICAL ASPECTS TO BUILDING DESIGN ACTIVITIES

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Abstract

In the submitted paper, a KBS for supporting the acoustical design of buildings is described. The main objective of this system is to allow the integration of the acoustical aspects in the building design activities, with a special emphasis on the necessity to consider the acoustical aspects during the early design stages, (i. e. Massing and Sketching), In fact, building design can be considered as a regulative, integrative process which can be divided into several stages. However, four design stages are commonly identified. Massing Design Stage, Sketching Design Stage, Preliminary Design Stage and Detailed Design Stage. In order to carry out the system, a set of tools should be proposed. These tools must allow the user (designer) to perform the different tasks related to acoustical design of a building in relation to i- the design stage and -ii the other areas which could be considered from an acoustical point of view as design constraints. In addition, they must enable use of the different strategies used in the design activities i. e. refinement prototypes and generation prototypes. Augmented Transition Networks are proposed to represent the acoustical design process, with this representation being based on the use of arcs and nodes. On finally the architecture of system is proposed.

1 INTRODUCTION

Building design is inherently complex because the design process involves a range of disciplines such as structural engineering, thermal engineering, foundation engineering..., and the objectives of the specific disciplines may often be in conflict with one another. Thus, a compromise is not only needed but is indispensable in order to have a satisfactory and global solution [1], with proper consideration also being given to economical aspects. Thus the proposed system must take into account the multitechnical aspects of building design. In order to account for these, the aspects can be considered as design constraints that tend to restrict the possible set of design solutions from an acoustical point of view to obtain the set of solutions which fulfils the other objectives to be satisfied by the building. Relationships between the acoustical component and the other components have been discussed in [2].

Building design can be considered as a generative, integrative and regulative process leading to the definition on one hand of volumes, shapes of rooms and apartments, etc., and on the other hand the definition of different elements to be constructed so that a set of pre-defined objectives is satisfied. Generally, four building design stages have been identified ; massing design stage (MSD), sketching design stage (SDS), preliminary design stage (PDS) and a detailed design stage (DDS). For each stage various tasks have to be defined, such as:

- identification of objectives to be achieved ;
- proposition of a set of design solutions ;
- performance evaluation of the proposed solutions ;
- comparison of performance with the stated objectives and the proposition, if necessary, of modifications, and ;
- the selection of the appropriate solution (i. e. the optimal solution) [3].

From this basis, the system must be able to allow the designers to perform these tasks. In addition, the system must enable the use of different approaches characterising the design activities [3,4].

Acoustical performance results from the combination of two types of performance : architectural performance and technical performance [5]. The greater the effort devoted to the acoustical aspects in the early design stages i.e. massing and sketching, the greater the savings in both time and cost. In fact, a good architectural design can avoid designers having to rely upon sophisticated solutions for achieving the stated performances, but this presupposes the existence of such design aids. Consequently, the system must enable designers to measure the impact of the architectural solutions on the technical issues to be adopted later on. In fact, the majority of the acoustical problems in buildings are due to architectural configurations. [6]

From a variety of perspectives, we contend that significant benefits can be realised by developing a design aid for assisting with the design activities. A knowledge based system with production rules has been chosen due to its several advantages for building design, particularly in the early design stages [7]. This paper describes an approach that develops this type of knowledge-based system.

2. ACOUSTICAL BUILDING DESIGN

Generally, the main objective of acoustical building design is to enhance the well being of the inhabitants from a sound perspective. This objective results generally from the conversion of the physiological, psychological, and social needs into stated performances to be reached, with these performances depending on technical issues and economic aspects. In fact, it is difficult to define the objective of a building without considering the possible solutions for achieving these objectives, hence there is an association between performance and solutions in terms of a search of the performance set and the corresponding solutions.

The main objective for acoustical building design can be divided into two sub-objectives : acoustical treatment and acoustical insulation [8]. The first former aims at finding the best conditions that allow good speech intelligibility and favouring good music clarity, fullness, etc. Whereas the latter consists of carrying out the appropriate elements so that the sound level received in one room is located within a range depending on the nature of sound, room purpose and so on,.. when an exterior noise source is emitted. However, in residential buildings which represent the focus of our research, the acoustical objective can be reduced, in a first approximation, to just the acoustical insulation. Acoustical insulation issues can also be divided into other sub-objectives such as airborne insulation, impact insulation, equipment insulation, etc. [8]

To determine the appropriate solution, designers are generally trained to identify the acoustical needs of a building. Then, the designers deduce the performances to be obtained, and propose a set of solutions permitting the satisfaction of the stated objectives. Once this step is achieved, the designers compare the performance of the solutions with the performance to be reached and finally choose the appropriate solution according to some criteria related to economic, cultural, and aesthetic factors. Two strategies will be adopted for designers to propose solutions [3]. These are :

- Prototype Refinement : The principle of this approach is to adapt and to place in context a set of design solutions which has been proven successful according to some criteria. This approach is suitable if the designer knows "a priori" the set of performances to be satisfied such as those within regulations and Qualitel's Comfort Label.[9] The advantages of this approach resides in the optimisation of the design process in the sense that this approach provides a direction for looking for a pertinent solution. However, a significant inconvenience is the limitation of creative aspects which characterise the design activities, since designers will not be motivated to look for a new set of design solutions and consequently this may lead to a uniform set of design solutions. This phenomenon generally will have negative effects on building innovations.

- Prototype Generation : This approach is based on the derivation of a new set of solutions "from scratch" by attempting to find the most appropriate solutions which relate to the pre-defined objectives. This approach requires that the designers start with the identification of the stated objectives and then to propose solutions which fulfil these objectives. This approach is more interesting in comparison with Prototype Refinement in the sense that it allows the formalisation of a set of performances and the evaluation of a set of design solutions which fulfil the identified objectives. A potential problem is that the definition of the objectives is a very difficult task because of the necessity to generate and test compatible, precise and analytically verifiable goals. This definition, which is possible only on strictly a theoretical level, is very difficult or even impossible to be achieved in practice due to time constraints. Therefore, designers often rely upon prototypical sets of objectives adapted from building codes, common practice, and past experience.

3 ACOUSTICAL BUILDING DESIGN PROCESS

Acoustical building design can be considered as a generative, integrative, and regulative process since, according to the stated objectives, the process starts by proposing an initial state, a set of geometrical elements, and then to direct the initial state, by adding or adjusting a new set of elements, towards a final state which enables the satisfaction of these objectives. That is, some intermediate states may be identified, with four sets of optimal states being identified. These four design stages, as shown in Figure 1, are identified as : massing, sketching, preliminary design stage and the finally detailed design stage [2,8]

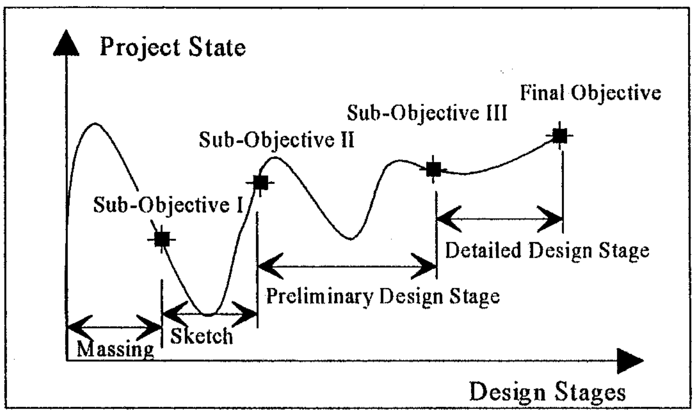

Fig. 1 : Acoustical design process

Regardless of the design, the main objective of the acoustical engineer is to protect the building inhabitants against all potential noises. The division of the design process, into four design stages, is not only necessary but indispensable for the following reasons :

- The acoustical designers can on one hand avoid resorting to sophisticated solutions which are required to satisfy the building performance or avoid rejecting the architectural solutions because there is no cost-effective solution to fulfil the objectives. Alternatively the solutions can not be implemented and thus a feed-back process seems indispensable in this case.
- The number of design constraints increases generally as design progresses. Consequently the set of design solutions to be proposed decreases. Hence is it important to consider the acoustical aspects from the beginning of the design process.
- Design process division allows stabilisation and the resolution of the conflict problems raised by the multitechnical aspects of building design. In fact, the division of the design process allows some optimal sub-states to be identified which serve not only as starting points for the next stage but also to direct the project to the final and optimal project state. In this way the designers can avoid review decisions which have been taken in previous stages and thus the design process is optimised.
- Due to this division, the designers can have a historical trace of the different states of the project being designed. This historical trace could be

used in the future to determine the impact of architectural solutions on the technical issues in the sense that it could allow the establishment of a correlation between the different states of a project which would serve to enrich the designer's knowledge.

The objective of the first design stage, "Level I", is to study the relationship between the building and its environment. In fact, the acoustical engineer can assure the protection of the integrity of the building with a judicious location and disposition of the building in relation to the surrounding noise sources [10,11]. In the second design stage "Level II", the acoustical engineer attempts to ensure a complementary integrity protection against outside noise by using features such as balconies, flat set backs, etc. [12] and to study the special distribution of rooms, apartments, and so on, in order to ensure the protection of rooms against inside noise sources. If the desired acoustical protection is not achieved, the acoustical engineer relies upon physical elements such as walls and windows. This is the objective of the third design stage, "Level III". The assessment related to this level is based on global values expressed in dB[A]. Sometimes this assessment can give misleading results, which is why acoustical engineers are trained to make spectral analysis and this is the objective of the fourth design stage, "Level IV".
In other words, for each design stage we must identify the different tools needed to perform the different tasks of design. These tools must fulfil the following operations :

- definition of the desired set of performance criteria (goals to be reached),
- production of alternative design solutions,
- evaluation of the expected performance of the alternative solutions,
- comparing the predicted performance with the desired performance and, if necessary, proposing the appropriate modifications to be made,
- co-ordination of the previous operations, in fact these operations are spread out over the design process. Thus the execution of one operation, at a given moment, depends upon the project state and on other conditions leading up to this operation, such as previous similar decisions that have been made.

Finally it is worth mentioning that there are two ways to optimise the design process :

- short-range optimisation : the objective of this type of optimisation is to reduce the number of iterations represented by the overlap of Objective Definition / Proposition / Evaluation / Modification, in the sense that the designer can rely upon previous knowledge acquired during previous experiences.
- Long-range optimisation : A feedback process could take place, especially if there are no technical solutions permitting the satisfaction of the objective related to one stage. In order to avoid this situation, the impact of solutions proposed in one stage must consider to some extent, the issues to be addressed in the following stages (which presupposes that such is permissible).

4 ACOUSTICAL DESIGN PROCESS MODELLING

To support creative acoustical design of residential buildings within a computer environment, a knowledge based system with production rules is considered extremely suitable for the following reasons : firstly the acoustical engineer often deals with uncertain and incomplete knowledge, particularly in the early design stages. Secondly, this system must assist the designer in the intuitive and judgmental operations of the process, thus the system must incorporate both prototype refinement and prototype generation modes of design. Thirdly, the system must help the designer to establish the different correlations which can take place between the different states of the project being designed for later use in the other design sessions. In other words, the system must be able to increase its knowledge through a learning mechanism. Fourthly, the system must allow the automatic generation of acoustical objects. And finally, the system must be able to establish a good relationship between the user and the machine.

Before implementing the system in a computer design process and acquiring the knowledge needed during the process, both the system and the knowledge must be structured. This will help the co-ordination and the harmonisation of the various design activities and allow for the orderly generation of comprehensive design solutions. Furthermore, this will also permit rapid access to comprehensive design knowledge, and answer the queries of the participants in each design phase. In fact, organising the design processes can provide methods, techniques and instruments that insure :

- Suitability of the answer to the stated need (new construction),
- Effectiveness of the design process (i.e. its convergence on an acceptable solution with minimum time requirements),
- Quality of the proposed solution (i.e. meeting pre-defined criteria and achieving design objectives)
- Current technological and organisational solutions,
- Recording of previously devised solutions and the performance levels they have achieved, to serve as a basis for future design, and to carry out the different correlations between the different states of the project relating to different design stages.

To carry out the knowledge-based system for supporting the activities of an acoustical engineer during the design process, a conceptual scheme must be proposed. The objective of this scheme is to structure the processed knowledge during the design process and to give a consistency to all rules written from the basis of this scheme. In fact, it is illusory to build a knowledge based system without identifying "a priori" the logical structure of this system.

The different types of knowledge needed to perform the acoustical building design must be modelled. Different models were proposed [2,8]. These models represent the different objects to be memorised but also the links between them. The first model concerns the surrounding environment such as roads, railway, etc.; the second model describes the building from an acoustical point of view; the third model represents building equipment and so on.

For describing the design process, Augmented Transition Networks technique will be used (ATN) [13]. Figure 2 represents the acoustical design process as a collection of nodes and oriented arcs which assure the links between nodes. Nodes correspond to the potential states of one project and the arcs represent the transition operators used to transit from one state to the another state, if conditions allow this. For example, transition operators are fired if a project state is sufficient so that a condition is fulfilled. Each arc has a label indicating the name of operator.

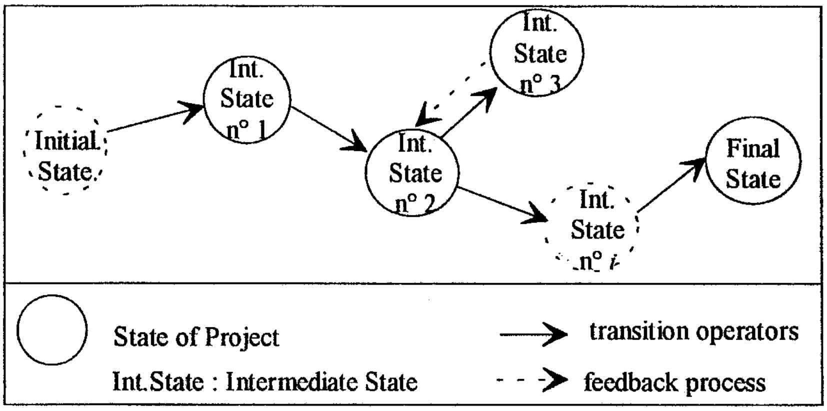

Fig. 2 : Acoustical design process representation (Augmented Transition Networks)

Figure 3 shows a detailed description of the first design stage, where one can see the different tools to be developed and the description of the project corresponding to this stage of the design stage. The tools which are used in this stage consist of some prototypes expressed as production rules, forming a small expert system. These rules are divided into sets, with each set dealing with specific aspects such as the implementation of residential buildings around an airport, another set for considering the surrounding roads, and so on. These rules are endowed with weighting values, which can be changed to some extent by the users, enabling the possibility of designer preference accommodation because, distinct from the regulations, the rules are subject to personal preference.
Figure 4 represents the "Level 3" of the design process, the project state corresponding to this stage is given and also the different tools to perform the associated tasks. The only difference in comparison with the first stage and the second stage (the second stage is not represented in graphic form) resides in the fact that two tools are used to choose building elements.

The first is represented as a small expert system which takes into consideration the different solutions proposed either by Qualitel and CSTB to address the objectives required by regulations [9,14]. The other one is a procedure which, from some criteria like a sound reduction index, proposes some solutions which can satisfy the stated performance.

5 KNOWLEDGE-BASED SYSTEM ARCHITECTURE

Figure 5 illustrates the architecture of the proposed system. This architecture accounts for the different notions which characterise the quality of CAD system (modularity, extensibility, adaptability, re-use) [15] For implementing the system within a computer environment, a knowledge object oriented language (KOOL) was chosen. KOOL is an environment which combines the Oriented Object Language with production rules [16].

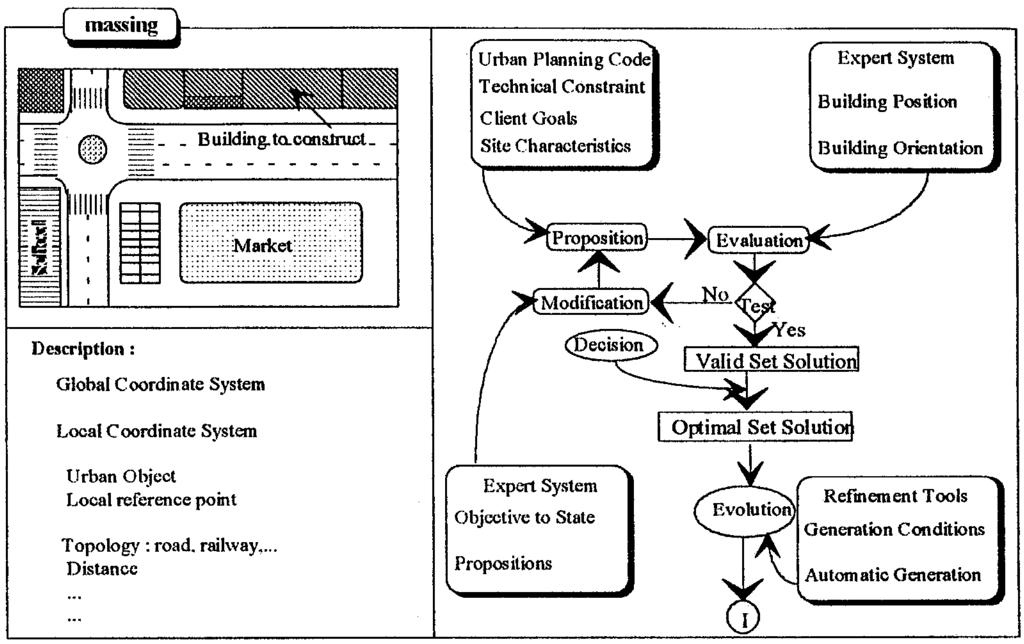

Fig. 3 : Level I of acoustical design process (description and tools)

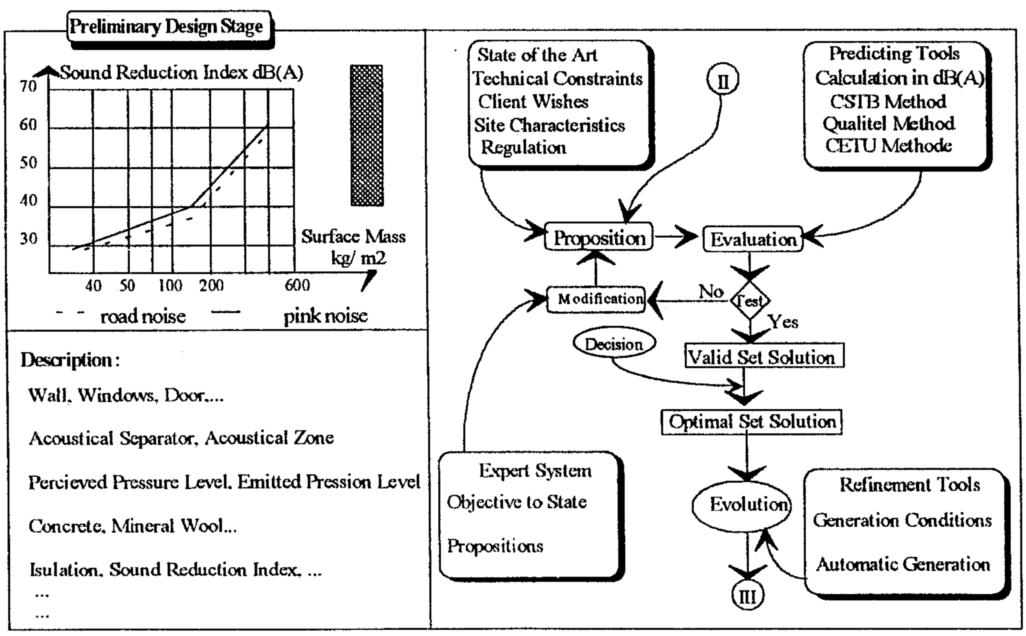

Fig. 4 : Level III of acoustical design process (description and tools)

The choice of this environment was made according to criteria previously mentioned. In fact, this environment allows a user to carry out the different strategies used in the design activities due to the capability for forward chain reasoning, backward driven chaining and finally, to middle chaining. In addition, KOOL is able to deal with uncertain and declarative knowledge which characterise the building context particularly in the early design stages (i. e. massing and sketching), and allows a user to build a powerful user/machine interface near to a natural language.

- Rules Base

In this rules base one finds the different rules used either for proposing a set of design solutions, or to evaluate the acoustical performance of a building, and if necessary, to propose the necessary modifications for the case where the performance is not achieved. Rules are organised in various Meta Rule Sets. Each set is specific to one design stage, and has different sub-sets relating to the different aspects to be considered.
A meta-rule set "MRS Level I" is proposed for studying the relationship between the building and its environment : implementation and orientation of a building on a site. This meta-set contains several sub-sets ; Airport Sub-Set (containing all rules used for considering the implementation of a building around an airport), Road Sub-Set (containing rules taking into account the orientation and implementation of a building besides existing roads), and so on. These rules are endowed with a weighted value representing the impact of the surrounding noise sources on the technical issues to be proposed later on. The designer has the possibility to modify, to some extent, the weighting of a rule or even to neglect the rule itself. These rules are driven by the goal. Special kinds of rules called meta-rules are used in order to optimise the process.

A meta-rule set "MRS Level II", is carried out to study of the location of rooms, flats, apartments. Similar to the first rule set this meta-rule set contains sub-sets, the objective of which is to study the superposition, juxtaposition and disposition of rooms between particularly acoustically critical rooms (i. e. living rooms and bedrooms). Also these rules are endowed with a weighted value which accounts for the impact of the room organisation on the technical issues discussed later.

Another, meta-rule, set "MRS Level III" is proposed to allow the designer to choose the different element structure of the appropriate solutions which have been shown to be satisfactory in practice. For example, solutions proposed by CSTB or Qualitel in order to answer to some objectives required by the regulations or recommended by the Qualitel's Association so that a Qualitel Label can be achieved and a grant possibly awarded.

Generic Classes Base

This base contains a general description of objects and concepts which correspond to a typical knowledge of concerning domain.

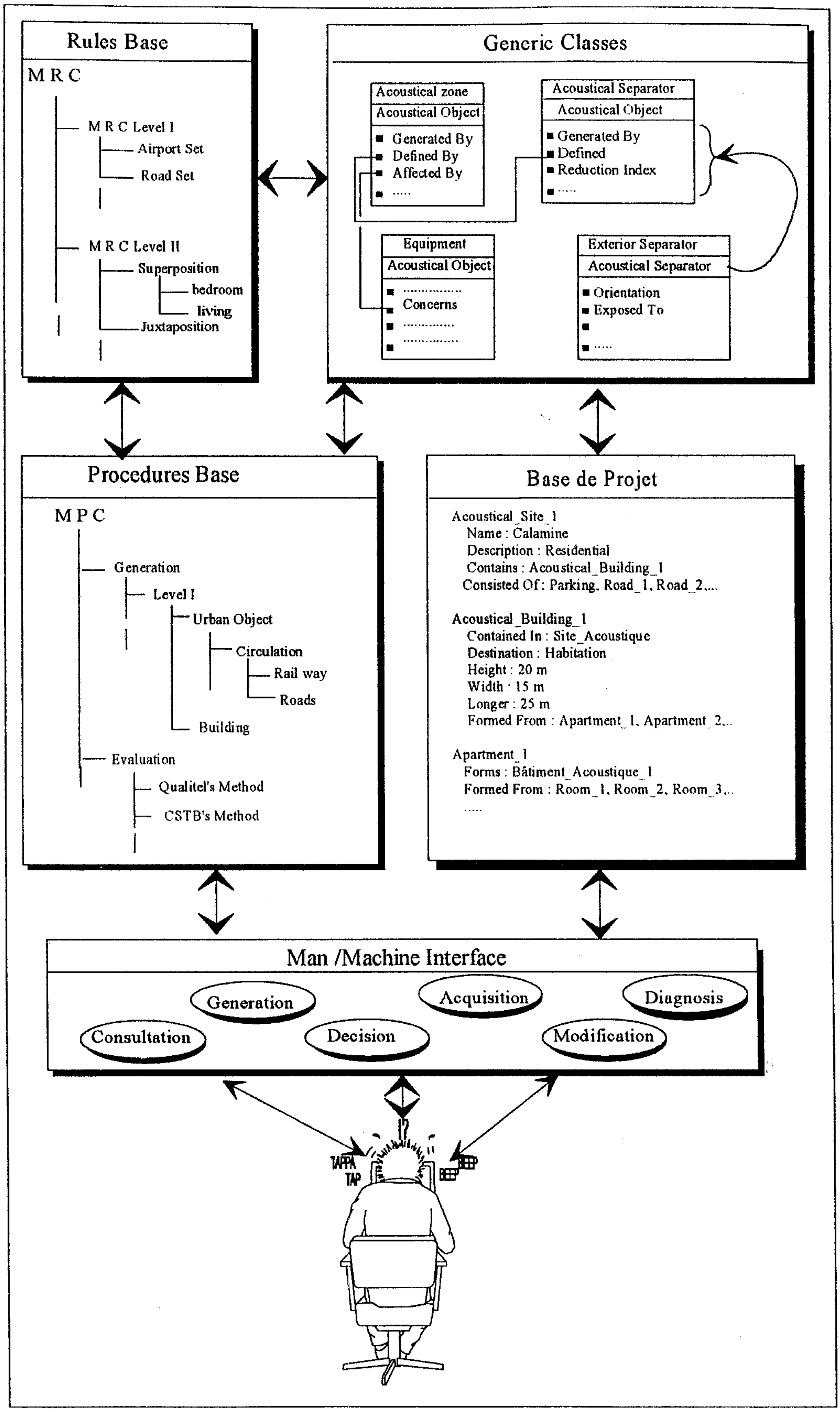

Fig. 5 : Architecture of the proposed KBS

This knowledge is represented throughout some logical models which aim at storing the different project states during the design process in the computer environment. The knowledge, which is represented by classes in NIAM's formalism, are discussed in [2,8]

Project Base

This base contains the different objects and knowledge which describe a given project and which are necessary to perform the different tasks of a design session.

Procedure Base

This base contains modules used for performing certain tasks needed for the generation of acoustical objects, and to evaluate the performance if certain conditions are satisfied.

Machine-Man Interface

Over the last few years, the importance of this module has been emphasised for the ergonomics of computer aided design systems. In fact, a system must provide the system's users with the capability to monitor the results of selected decision on the chosen solution, to give explanations , and so on. Various tasks are carried out : consultation, modification, decision, diagnosis and finally information acquisition. The majority of these tasks have been implemented as demons attached directly to the classes of objects. Distinction is made between three types of demons : Whenfilled, ToCompute, and Question [15].

6 CONCLUDING REMARKS

In this paper we have described the set-up of a knowledge-based system for supporting the acoustical building design process. For carrying out the system, the different functions of the system have been underlined. In fact, in order to allow a creative acoustical building design, the system must offer the possibility to use different approaches characterising the design activities (i. e. prototype refinement and prototype generation). To be able to implement the system in a computer environment, the design process was analysed and then structured. The main characteristics of the environment were emphasised. In relation to these characteristics, KOOL was chosen and the architecture of the system was proposed and explained.
A knowledge-based approach with production rules was utilised due to its potential features. In fact, the approach allows an easier up-dating of knowledge, and a powerful Man-Machine interface in the sense that it allows the simulation of the different strategies used by a designer performing acoustical design activities. In addition, the approach is appropriate to support the different treatments used during the design process (i.e. declarative treatments for the early design stages and algorithmic treatments for the later design stages), and finally the approach permits the automatic generation and a dynamic modification of the different states of a project.

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