DEDALE :
AN EXPERT SYSTEM FOR THE CONSTRUCTION AND THE RESOLUTION OF MULTICRITERIA DWELLING DESIGN PROBLEMS

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SUMMARY

The works presented in this paper concern the use of a rule-based system, furtherly interfaced with the CAD system "X2A" [1], to provide an aid to the designer in building and solving multicriteria problems.

Since the building quality is evaluated with several points of view (architectural, thermal, acoustical, economical ...), we can consider the problem of dwelling design as a multicriteria decision making problem.

So instead of considering dwelling design as an iterative process of generating and evaluating alternative solutions until a satisfying one is found, we propose an iterative process of generating and solving restricted multicriteria problems.

We present in this paper a prototype of an expert system, not yet definitive, dedicated to the four tasks :

1°-modelisation of the dwelling project

2°-selection of a strategy for modifications

3°-construction of a restricted multicriteria problem (according to the strategy)

4°-management of the resolution process.

1. Introduction

Dwelling design involves a large number of different experts in the process. To ensure the quality of a dwelling project (considering architectural, thermal, acoustical, economical ... points of view) we have thus to work on a great number of design variables and in taking into account a great number of criteria.

If we can consider the problem of dwelling design as a multicriteria decision making problem, it is not realistic to imagine a computerized process based on the research of the Pareto set of solutions [2] [3] and on the selection of a particular solution in this set.

But we have to acknowledge as a fact the limitations of present Dwelling-CAD systems [4], concerning decision making aid.

The use of simulation models and iterative procedures does not ensure the project quality, but only allows the study of multiple different solutions. We have thus to propose a design aid procedure based on both simulation models and decision models. Since the use of multicriteria optimization tools can be considered only for restricted problems, these decision models must be constructed during the design process and based on an analysis of the performances corresponding to the current proposal of the designer.

It is for these tasks (analysis of the project quality, construction of restricted multicriteria problems) that the rule-based systems seem to be opportune tools in CAD.

2.1. Design as "Problem Setting"

The design process involves the resolution of a design problem in which the numerous performance variables, not always well defined, are in complex relationships with each other.

From this "ill-structured problem" (H. SIMON) [5], the design problem is decomposed into a lot of well-structured subproblems, during the design process.

As J.L. LE MOIGNE [7] and G.F. LANZARA [6], we can so consider design activity both as "Problem Solving" and "Problem Setting".

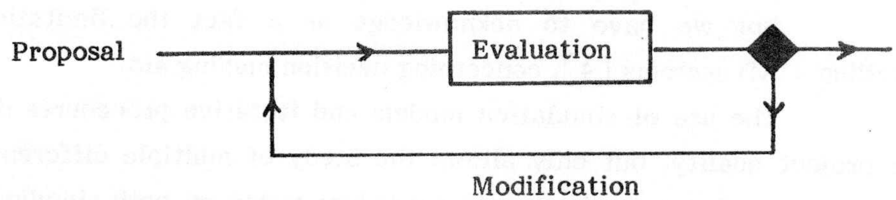
The design process can be represented by the following scheme :

problematical situation ⟶ (sub)problem(s) ⟶ solution(s)

Starting from a problematical situation (conflicting goals and design contraints) the first task is to define a well structured problem or a collection of well structured subproblems. The second task is to find solutions to these problems.

Let us see how we can illustrate these principles in dwelling design, and how we can guide our research for an efficient Computer Aided Design system.

The functionning of present Dwelling-CAD systems is based on the following scheme :



The designer propose technical solutions, the CAD system evaluates the consequences of this proposal (thermal, acoustical ... economical performances). If the results are not satisfying, the designer has to modify his proposal.

If we want to ensure both the quality of the project and the reduction of studies costs and delays, we have to guide the designer during the research of a "better solution".

The control of design process so appears as a problem of Quality Control.

The principles of Quality Control [4] allow to define four control phases, which are fundamental in every production process :

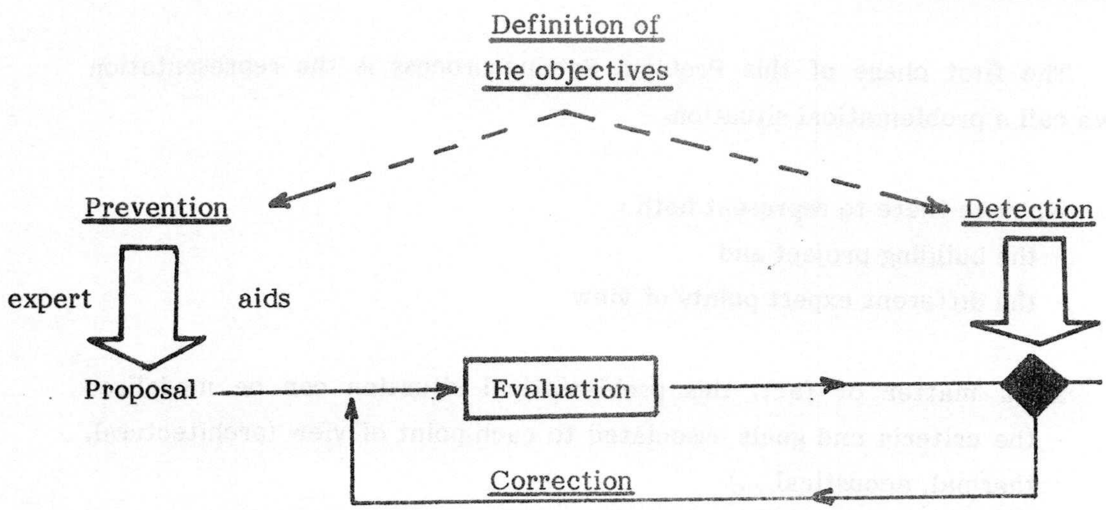
1°-Definition of the objectives

2°-Prevention : to avoid production of non qualities

3°-Detection : to compare the results to the objectives

4°-Correction : to do corrective actions to suppress the non qualities

If we superpose these control phases upon the principle scheme of above, the modifications aid problem becomes a correction problem.



This modifications problem, i.e. the correction phase is a problem of choice : which design variables have to be modified, considering the performances obtained, and taking into account that an action usually leads to numerous and often conflicting consequences ?

So this correcting phase in the design process can be represented by the following scheme :

Starting from a representation of a problematical situation (goals, project's performances, relationships between performances) a restricted multicriteria problem can be generated, then resolved, to propose to the designer a set of alternative modifications of the project.

This process can be decomposed in four phases :

<u>Problem-setting</u>

1. representation of the problematical situation that means modelisation of the building project
2. identification of a crucial weak point that means selection of an action strategy
3. construction of a restricted multicriteria problem (according to the strategy)

<u>Problem-solving</u>

4. resolution of this multicriteria subproblem

2.2. Design as Modelisation

The first phase of this Problem Setting process is the representation of what we call a problematical situation.

We have there to represent both :

- the building project and
- the different expert points of view

As a matter of fact, this problematical situation can be modelised by :

- the criteria and goals associated to each point of view (architectural, thermal, acoustical ...)
- the performances of the building project
- the relationships between these criteria or performances.

It is from this model that we can then elaborate an action strategy (based on a representation of the conflicts between points of view) and construct a restricted multicriteria problem.

This modelisation involves the representation of the simulation models used by the different participants in the design process :

each connection between a design variable and a criterion must be explicit to allow the representation of conflicts and the construction of a restricted multicriteria problem.

We have to notice that databases used in CAD systems do not include this explicit representation : they only represent the structure of the virtual building (decomposition into entities : floors, flats, rooms and components, and relationships between these entities). Present CAD systems can be regarded as juxtapositions of databases and algorithms, where algorithms can be considered as "implicit knowledge", "black boxes".

To realise a genuine Computer Aided Design system, we have so to make this knowledge explicit :

implicit knowledge for calculation	⟶	explicit knowledge for computation

What is modelisation of the building project :

(1) * Project database (geometrical and physical model)

* Algorithms (for drawing and evaluation)

* Explicit representation of evaluation models

(2) * Performances to compare to goals

(3) * Relationships between performances and design variables

* Relationships between performances

(1) : structural model of the building project

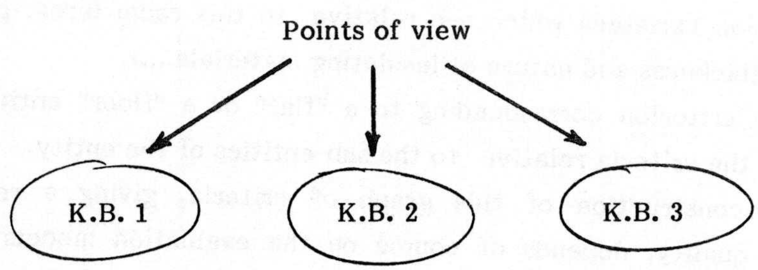
(2) : functional model of the building project

(3) : connections between points of view

2.3. Artificial Intelligence for Modelisation

As we introduce it before, an explicit representation of evaluation models used in the CAD system is necessary to control the design process.

Construction of this explicit model of designers knowledge is a pure symbolic data processing. For this task rule-based systems are particularly appropriate.



From the knowledge bases, associated to the different points of view, in which we can represent the evaluation models, and from the project database, we can infer a representation of the relationships between the project performances and the project variables or between the performances.

In the second part of this paper we present how rules will be used in the expert system DEDALE :

1°-to build a representation of the building project

2°-to use this model to select a strategy for the modification of the project

3°-to use this model to build a restricted multicriteria problem

4°-to control the resolution process of this subproblem

3. DEDALE : an Expert System for Dwelling Design

3.1. Modelisation of the Dwelling Project

The representation of the evaluation models used in the CAD system, i.e. the modelisation of the project quality is based on a double decomposition of the building :

a) structural decomposition : as we must be able to analyse the project quality to determine the non qualities roots, we have decompose it in accordance with the hierarchical decomposition of the building :

building - floor i - flat i,j - room i,j,k

b) functional decomposition : the definition and the appraisal of the quality of any entity of the building project needs the definition of a vector of criteria which represent the functions of this entity

Each criterion corresponding to a "room" entity is defined as a function of all the decision variables which are relative to this room (area, glazing area, glazing nature, thickness and nature of insulating materials ...).

Each criterion corresponding to a "flat" or a "floor" entity is defined as a function of the criteria relative to the sub-entities of the entity.

The construction of this graph of criteria, giving a representation fo the project quality, depends of course on the evaluation models used in the CAD system.

So, rules used to build the graph are representations of the evaluation models :

R1 : if : the entity F is a flat
if : the entity R is a room of flat F
then : criterion "B" (heat needs) associated to the flat F depends on criterion "GV" (heat losses) associated to the room R

R2 : if : the entity F is a flat
if : the entity R is a room of flat F
if : the room R has a window
then : criterion "B" associated to the flat F depends on criterion "A-S" (solar gains) associated to the room R

R3 : if : the entity R is a room
if : the entity R has a window
then : criterion "GV" associated to R depends on design variable "SVIT" (glazing area)

R4 : if : the entity R is a room
if : the room R is a living room or a bedroom
if : the room R has a window
then : criterion "LEXT" (Sound Insulation) associated to R depends on design variable "SVIT"

* <u>correlations between criteria</u>

As we underline it before, the project quality modelisation must allow the definition of non qualities roots, i.e. of the possible actions to suppress them and must represent all the relations between performances.

These relations or correlations are from two types :

. correlation between two criteria which depend on a same design variable or on a same criterion

CRITERIA :	sound insulation	thermal loss
DESIGN VARIABLE :	glazing area	

These correlations are only relative to the simulation models used in the CAD system.

. correlation between two criteria which depend on two criteria or on two variables which are dependant :

* interactions between design variables

These interactions are closely relative to the construction rules adopted for the project. As a matter of fact, if the designer decides to put a only one frontage sandwich type on each building frontage, the "frontage sandwich nature" variables relatives to all the rooms of this frontage will have the same value.

Thus, the interactions between two design variables are defined from :

1-the building composition

2-the construction rules adopted for the project.

Thanks to the modelisation principles, the different consequences of an interaction between two variables are simply deducted by an ascending exploration of the graph of criteria.

* numerical model

The graph of criteria relative to the project and the correlations between criteria allow :

_ to define, among the set of possible actions, a set of actions which can reduce or suppress a non quality

_ to define, for one of these actions, the set of all its consequences.

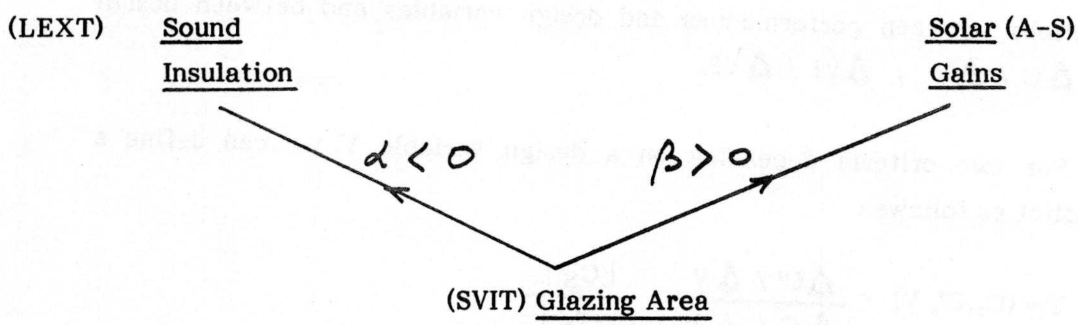
This first stage of decision aid must be completed by numerical informations : as a matter of fact, the definition of a strategy for modifications of the project involves a numerical evaluation of the conflicts between objectives.

R1 :	if :	criterion "B" of flat F depends on criterion "GV" of room R
	if :	the performance associated to "GV" is modified :
		$GV \longrightarrow GV + \Delta GV$
	then :	the performance associated to criterion "B" is modified :
		$B \longrightarrow B + \Delta B$
		with $\Delta B = \Delta GV$ * (Area of P / Area of F)

R2 :	if :	criterion "GV" of room R depends on design variable "SVIT" (glazing area)
	if :	the value of "SVIT" is modified : SVIT $\longrightarrow$ SVIT + Δ SVIT
	if :	the value of "NVIT" (glazing nature) is "single glass"
	then :	the performance associated to criterion "GV" is modified and ΔGV = (- 0.06) * Δ SVIT

Rules like R1 and R2 represent numerical relationships between performances, or between design variables and performances. This allows to predict the different consequences of an action and to represent conflicts between points of view.

example of a conflict :



. ΔLEXT / Δ SVIT $<$ 0 :

sound insulation is reduced if the glazing area is increased

. ΔA-S / Δ SVIT $>$ 0 :

solar gains are increased if the glazing area is increased

As we introduce it before the modelisation of the building project (a graph of criteria with numerical relationships) allows to help the team of designers to :

1°-select a strategy to modify the project

2°-to set restricted multicriteria problems

3.2. Selection of a strategy

As we consider design process as an iterative process of generating and solving, restricted multicriteria sub-problems, we have, to be sure to reach the goals, to define a strategy for the construction of the successive problems.

We chose to build this strategy on three notions or three measurements relatives to a criterion or a performance :

- relative difference between performance and goal
- number of design variables (not fixed) on which the designer can work to reduce the difference between performance and goal.
- rate of conflict of the criterion

This last measurement is based on the numerical representations of the connections between performacnes and design variables, and between design variables : $\Delta C / \Delta V$, $\Delta V1 / \Delta V2$.

For two criteria depending on a design variable V we can define a rate of conflict as follows :

$$T_C (C, C', V) = \frac{\Delta C' / \Delta V}{\Delta C / \Delta V} \cdot \frac{| C_S |}{| C'_S |}$$

(C_S and C'_S are the goals corresponding to C and C').

For a criterion C we can define a rate of conflict :

$$T_C (C) = \frac{1}{n} \cdot \sum_{i=1}^{n} T_C (C, (C', V)_i)$$

(C'_i : every criterion connected to criterion C by a design variable V_i).

Among the different non qualities of the project (performances inferior to corresponding goals) we can select a weak point in considering two of the three notions introduced before, this non quality then becomes the core of the restricted multicriteria problem to build :

H1(20) : Criterion C is selected

if : $C < C_S$

and if $| C - C_S / C_S | \geqslant 20\ \%$

H1(10) : Criterion C is selected

if : $C < C_S$

and if : $| C - C_S / C_S | \geqslant 10\ \%$

H2(2) : Criterion C is selected

if : $C < C_S$

and if : the number of non fixed design variables connected to C is $\leqslant 2$

H3 : Criterion C is selected

if : $C < C_S$

and if : $T_C(C) < 0$

These four rules are combined to select the weak point :

H12(20,2) : Criterion C is selected

if : C verifies H1(20)

and if : C verifies H2(2)

H12(10,2) : Criterion C is selected

if : C verifies H1(10)

and if : C verifies H2((2)

H13(20) : Criterion C is selected

if : C verifies H1(20)

and if : C verifies H3

H13(10) : Criterion C is selected

if : C verifies H1(10)

and if : C verifies H3

H23(2) : Criterion C is selected

if : C verifies H2(2)

and if : C verifies H3

To control the research of the weak point a set of second order rules is defined. These rules allow to determine which rule has to be applied :

HH1 :	if :	H12(20,2)	has no solution
	and if :	H2(2)	has solutions
	then :	try to verify H12(10,2)	
HH2 :	if :	H12(20,2)	has no solution
	and if :	H1(20)	has solutions
	and if :	H2(2)	has no solution
	then :	try to verify H13(20)	
HH3 :	if :	H12(20,2)	has no solution
	anf if :	H1(20)	has no solution
	and if :	H2(2)	has no solution
	then :	try to verify H13(10)	
HH4 :	if :	H12(10,2)	has no solution
	then :	try to verify H23(2)	
HH5 :	if :	H13(20)	has no solution
	if :	H3	has solutions
	then :	try to verifiy H13(10)	

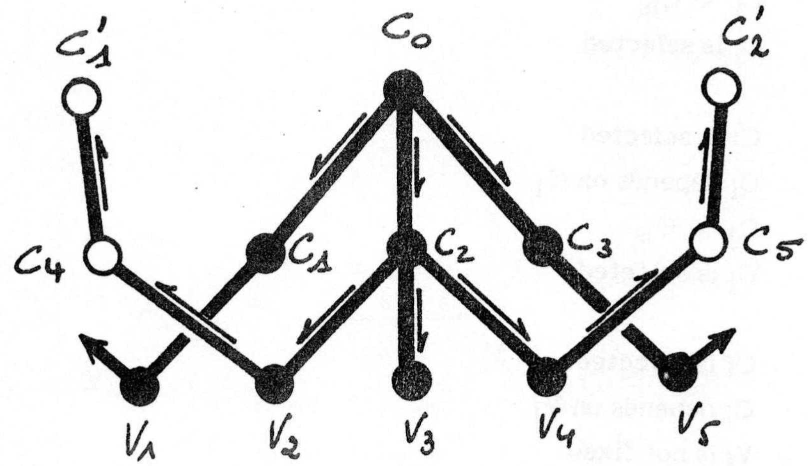
At least, when no rule among H12( ), H13 ( ) and H23( ) can be verified, a set of rules allows to define a weak point :

HS1 :	if :	H23(2)	has no solution
	and if :	H3	has solutions
	then :	the weak point Co is one of the solutions of H3	
HS2 :	if :	H23(2)	has no solution
	and if :	H3	has no solution
	then :	the weak point Co is one of the solutions of H2	

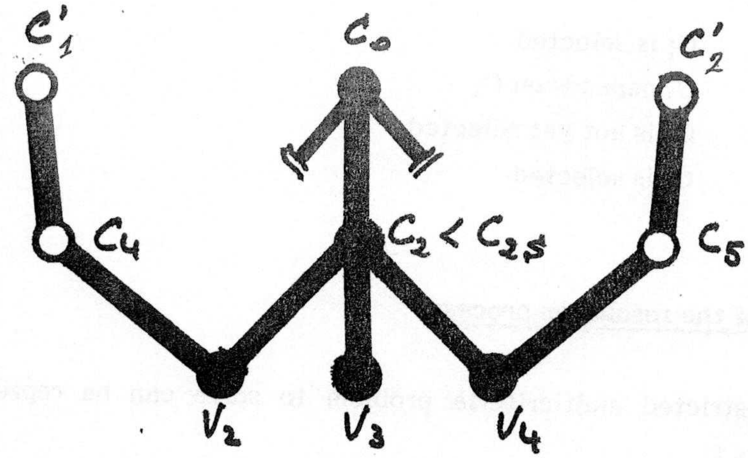
--- etc.

3.3 Construction of a restricted multicriteria problem

Rules presented above permit to determine a crucial non quality which has to be the core of the multicriteria sub-problem to be constructed. Starting from this criterion Co and using the rules for modelisation presented before (3.1) we can define the criteria and design variables connected to Co :



From this sub-graph of criteria we can define a restricted problem in selecting among sub-criteria of criterion Co those which correspond to non qualities :



This sub-graph represents the multicriteria sub-problem to study. For the example of above we have 6 criteria, and 3 design variables for which we can precise a set of possible values.

Rules used to build this restricted multicriteria problem are the following :

S1 :

	if :	Co depends on C_i
	and if :	$C_i < C_{is}$
	then :	C_i is selected

S2 :

	if :	C_i is selected
	and if :	C_i depends on C_j
	anf if :	$C_j < C_{js}$
	then :	C_j is selected

S3 :

	if :	C_i is selected
	and if :	C_i depends on V_j
	and if :	V_j is not fixed
	then :	V_j is selected

S4 :

	if :	V_i is selected
	and if :	C_j depends on V_i
	and if :	C_j is not yet selected
	then :	C_j is selected

S5 :

	if :	C_i is selected
	and if :	C_j depends on C_i
	and if :	C_j is not yet selected
	then :	C_j is selected

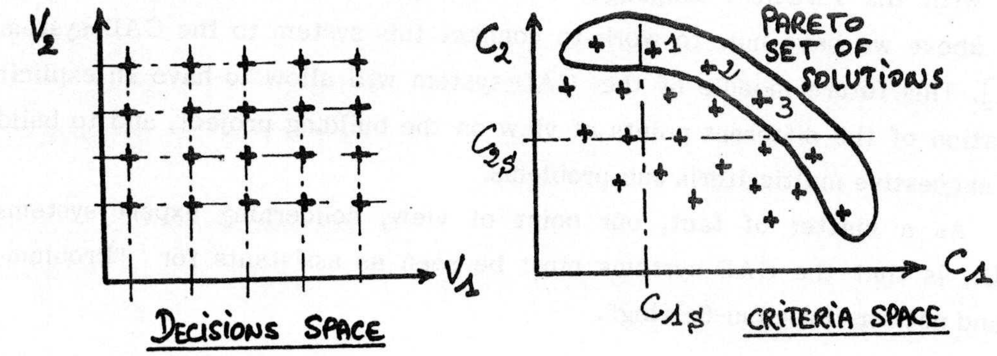
3.4. Management of the resolution process

The restricted multicriteria problem to solve can be represented by the following terms :

- n criteria : C_i associated to
  goals : C_{is}
- p design variables : V_k

Solving this sub-problem means finding a combinaison of values of the design variables V_k which verifies : $C_i \geqslant C_{is}$, i = 1, ..., n.

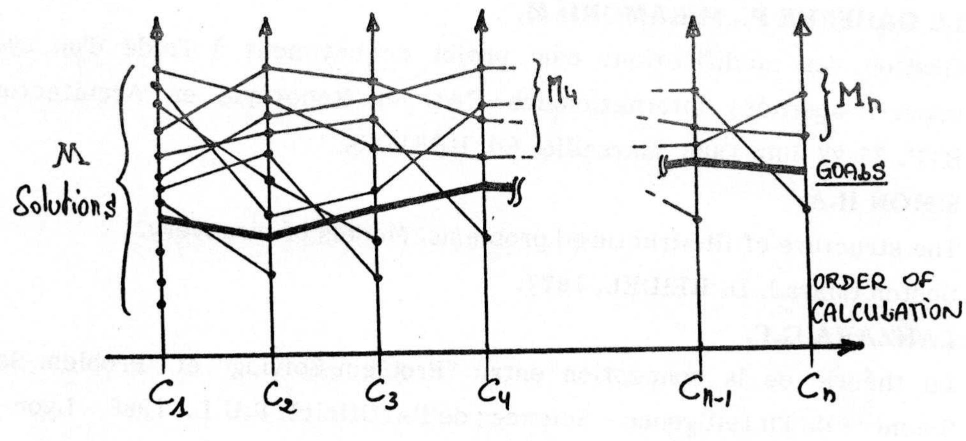
For a two criteria - two design variables problem we can represent the decisions space and the criteria space as follows :



For the example presented above the objective is to find one of the three solutions 1, 2, 3 which belong to the Pareto set and which verify the objectives $C_i \geqslant C_{is}$.

If each design variable V_k has m_k possible values, the number of alternative solution is $M = \prod_{k=1,...,p} m_k$

To reduce the number of calculations, we only consider, at each stage of the calculation process (evaluation of criterion C_i), the M_{i-1} solutions which verify : $C_j \geqslant C_{js}$; j = 1, ..., i-1.



After calculation of all the n criteria we have to select, among the M_n solutions obtained, those which belong to the Pareto Set.

CONCLUSION

What we have presented in this paper are the principles of an expert system intended to help the team of designers to build and solve multicriteria sub-problems. The system proposed has been partly experimented on personal computer with the PROLOG language. To experiment more precisely the rules presented above we have now to work to connect this system to the CAD-system "X2A" [1]. This future module of the CAD-system will allow to have an explicit representation of the different points of view on the building project, and to build and solve successive multicriteria sub-problems.

As a matter of fact, our point of view, concerning expert systems for C.A.D., is that the CAD-systems must be seen as assistants for "Problem-Setting" and not for "Problem-Solving".

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