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Multicriteria and Multiple Actors Tool Aiding to Optimise Building Envelope at the Architectural Sketch Design

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Abstract. The PC software AMCE is proposing building actors (owner, project authors…) a Multiple Criteria Decision Aid procedure (MCDA) to optimise the building envelope about cost and energy performances, during the sketch design.

Two main modules are linked, where the user interactively goes:

– the first one manages parameters describing the project requirements;

– the graphic pen-based module allows to draw the sketch; it calculates geometric parameter values and put them back in the first module.

Permanently informed on forseeable performances, the user can any time search for optimal scenario giving best satisfaction (monoactor optimisation) or most preferred compromise (muliactors optimisation).

Key words: architectural sketch design, energy, MCDA, feasibility study, Promethee.

1. Introduction

This paper presents the last update of the one written with G. Colson (1999) for Como 49th Meeting of the European Working Group *MultiCriteria Aid for Decisions*, first updated for the 51st Meeting held in Madrid (Hauglustaine, 2000) and later for the publication in the 49th and 50th Meeting Proceedings (Colson and Hauglustaine, 2000).

The approach is an attempt to cope with the difficult problem of ameliorating the dialog between the several actors intervening in the design of a building envelope, using MCDA methodologies. The main purpose is to present the MCDA framework which can help *the sketch design*, the earliest step, besides being a crucial one, in the whole building envelope design.

We can consider three stages that lead actors to the sketch design (see Fig. 1). The first is a definition and negotiation stage between several private and public actors, where they express their requirements and preferences, based on several criteria, parameters, regulations and constraints. In the second stage, the actors build several scenarios by defining

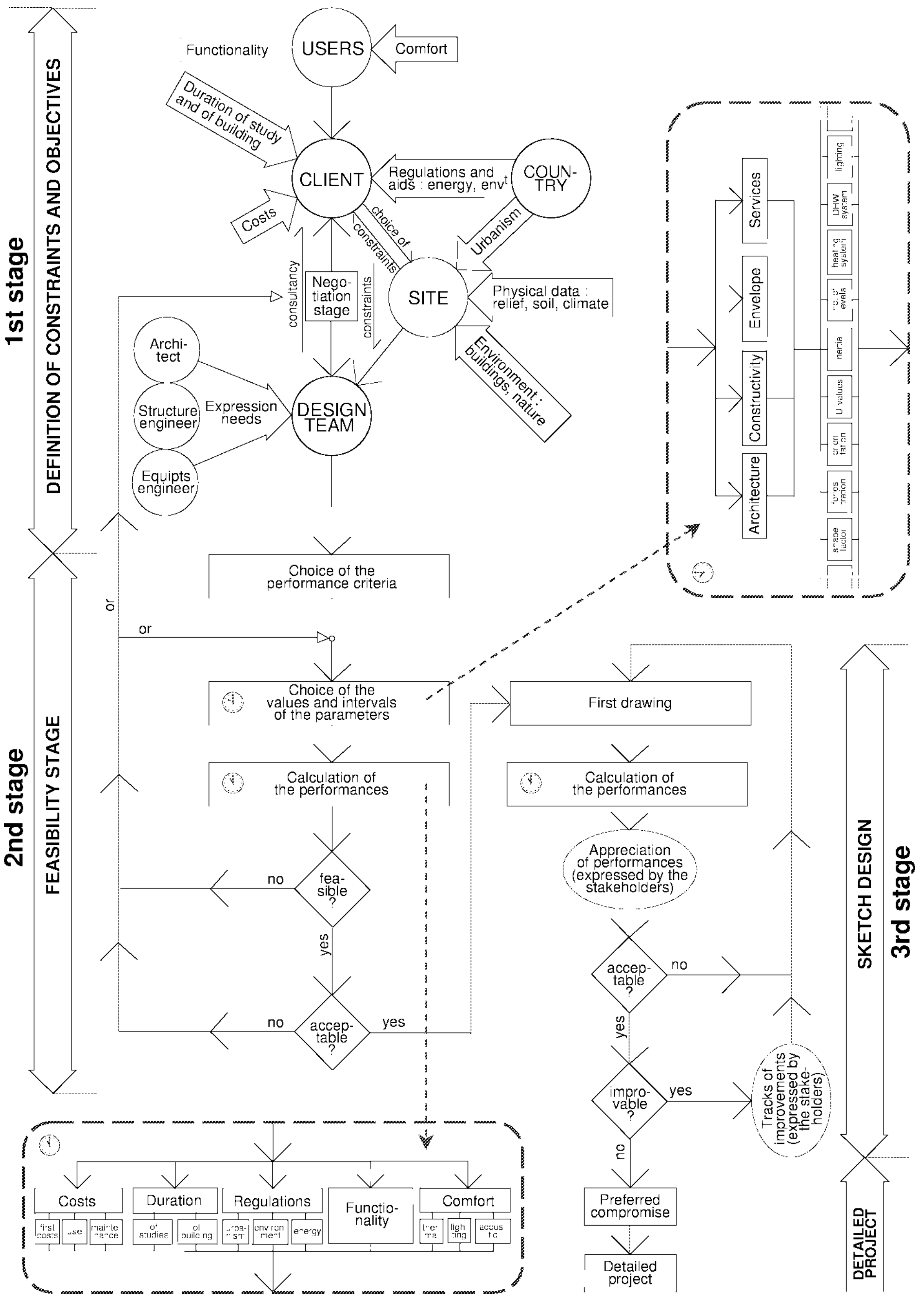


Fig. 1. The preliminary stages of the design process.

parameters and assessing their values, with some imprecision and tolerance. The architect or some expert system then computes performances on the various selected criteria. This second stage is called the feasibility stage, because it results in two questions: *Is the scenario feasible? Is the scenario acceptable to the stakeholders?*

Loops are introduced in the process when negative responses are given to these questions, until entering the third stage, the actual sketch design, becomes possible. After a first drawing of the project, performance calculations can be refined. The stakeholders then judge these performances as acceptable or not, and improvable or not.

Loops are envisaged in the case of non-acceptability or improvability, using a genetic algorithm procedure:

- each actor is able to search for the optimal set of strategic parameters, which corresponding scenario gives the most satisfactory performances according to the criteria he considers as relevant;
- all the actors may try to find the preferred compromise, defined by the values of strategic parameters which scenario is giving the best performances that equally satisfy all the actors together.

2. Multiple Actors Feature of the Building Design Process

The design process of a building is typically interactive, requiring the participation and mandatory satisfaction of several actors, each facing to multiple criteria decisions:

- The *client* initiates the whole operation; he may be the property developer, the owner, but also a future occupant or a future user… He is increasingly involved in the design process and in the search for design fitness to correspond to his requirements. Furthermore, the client's legal responsibility continuously increases, as does his responsibility in the building act. He's well personally responsible for his building's energy performance, the environmental protection, etc.

  Faced with these new duties, the client requests increased help from the design team. The project should allow the client to assume his new responsibilities, while reaching his objectives of cost, building period duration, comfort and functionality. The client is considered, however, as having no technical capacity, so the software should ask soft questions, using familiar vocabulary.

- The *project author* is a generic term that more often designates the architect, but also the consulting engineers (for structure, equipment…), the quantity surveyor, the project manager, etc. The project author's mission is so heavy, he often neglects matters he considers as non-essential, e.g., the energy aspects. Though a great deal of software is available to compute energy performance, it is, unfortunately, rarely used by architects, in practice. Software should help project authors in their task, while maintaining their particular objectives, e.g., their expressed needs and their wish for increased notoriety.

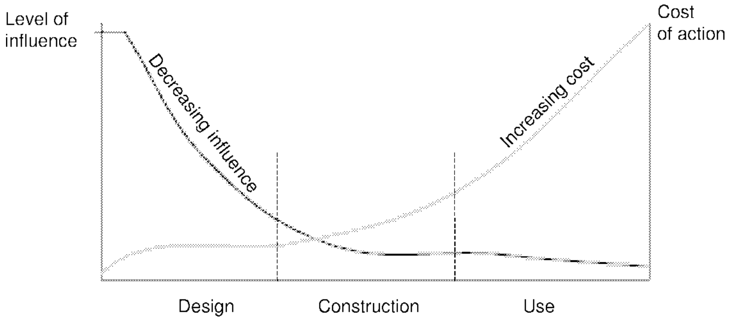


Fig. 2. Influence of decisions taken along a project on their corollary adjustment cost, in function of the moment when they are taken.

- The *public authorities, representing the country or the region,* are authors of constraining lawful and normative standards (thermal, urbanistic or environmental regulations, etc.); some public policies are translated into constraining levels of energy performances.

Finally, we see that the goal of the MCDA process and the linked software is to help each actor express his particular needs, either in the form of constraints or multiple objectives as well as to build an interactive tool, capable of dialoguing with each actor in his own language, while providing useful performance indicators.

Every architectural project is progressively defined, necessitating frequent interrogations to the actors and making the corresponding adjustments (Conan, 1989). The software should thus be able to allow for these frequent data adjustments.

When adjustments essential to the project viability are discovered too late in the design process or during the construction itself, they lead to additional costs, very often out of proportion when compared to their actual importance. Fig. 2 gives an expression of the influence, on the corollary adjustment cost, of the decisions taken along a project, in function of the moment when they are taken (Ali Mohamed and Hens, 1999).

A first feasibility check of the project is important, in order to ensure that at least one solution exists. The feasibility study enriches the negotiation and/or incites the actors to negotiate the objectives and the associated means again, when the solution set is empty.

While remaining very imprecise in the feasibility stage, project data may be sufficient to define a “scenario” (Roy, 1993; Maystre and Bollinger, 1999) that characterises the architectural choices and allows evaluating resulting performances.

3. AMCE Software: an Interactive Tool for Introducing Technical and Preferences Data and Evaluating Sketch Design Performance

AMCE is an acronym for “**A**id to the **M**ultiple criteria **C**onception of the building **E**nvelope” *(in French:* **A***ide* **M***ulticritère à la* **C***onception de l’***E***nveloppe de bâtiment).* The software is developed in both French and in English, with the programming language Allegro© Common Lisp (Franz Inc.). It runs on a common PC, with the following minimal characteristics: a 120 MHz Pentium microprocessor, Windows 95, 98 or NT 4.0 operating system, 15 Mb hard disk capacity, 32 Mb RAM storage capacity (64 Mb recommended) and a SVGA graphic card with a palette of 64.000 colours.

The usual starting point in energy software is the drawing of the sketch design itself: this approach lacks a first parametric phase, which allows defining a set of feasible solutions, among them, the preferred choice (Crawley *et al.*, 1998; De Wilde *et al.*, 1998; Rivard *et al.*, 1995). In our proposed design procedure, each actor chooses – and manages – the values of the *main parameters*, in order to satisfy selected criteria, based on individual preferences and requirements.

AMCE has been built to facilitate an interactive introduction of technical and preference data by each actor, based on his individual needs and capacity, and to compute performance criteria.

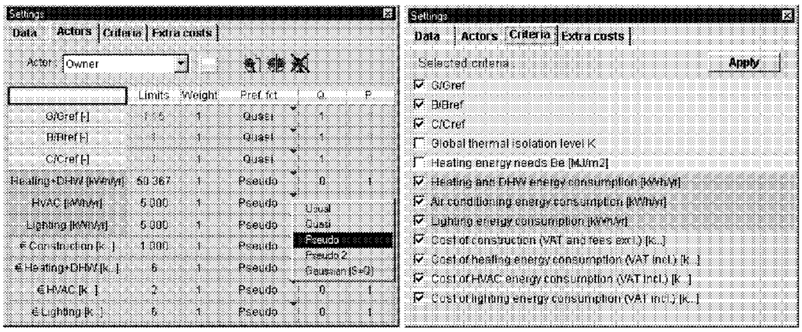
3.1. *Selected Criteria: Project Performances*

The software evaluates performances concerning energy aspects for heating, air-conditioning, domestic hot water and artificial lighting, as well as construction and use costs of the project:

- four regulation performances: K-level (as required in Flanders and Wallonia), Be heating energy needs (in Wallonia), G/Gref, B/Bref, C/Cref (in France);
- yearly energy consumption expressed in physical units (kWh), for heating and domestic hot water (DHW), air-conditioning (HVAC), and artificial lighting;
- associated energy consumption costs, i.e., use costs;
- project construction cost, VAT and fees excluded.

3.2. *Actor's Preferences: Choice of Criterion Types and Thresholds*

The architect, owner, tenant, property developer, etc., anyone intervening in the building process, can participate in its elaboration. Each actor defines a "scenario" summarising his desiderata and requirements. With the button "Actor's preferences", he defines his preferences (Fig. 3):



Actor: Owner

	Limits	Weight	Pref. fct	Q	P
G/Gref [-]	1,5	1	Quasi	1	
B/Bref [-]	1	1	Quasi	1	
C/Cref [-]	1	1	Quasi	1	
Heating+DHW [kWh/yr]	50 367	1	Pseudo	0	1
HVAC [kWh/yr]	5 000	1	Pseudo		
Lighting [kWh/yr]	5 000	1	Pseudo		
€ Construction [k..]	1 000	1	Pseudo		
€ Heating+DHW [k..]	6	1	Pseudo		
€ HVAC [k..]	2	1	Pseudo	0	1
€ Lighting [k..]	6	1	Pseudo	0	1

Selected criteria:

☑ G/Gref
☑ B/Bref
☑ C/Cref
☐ Global thermal isolation level K
☐ Heating energy needs Be [MJ/m2]
☑ Heating and DHW energy consumption [kWh/yr]
☑ Air conditioning energy consumption [kWh/yr]
☑ Lighting energy consumption [kWh/yr]
☑ Cost of construction (VAT and fees excl.) [k..]
☑ Cost of heating energy consumption (VAT incl.) [k..]
☑ Cost of HVAC energy consumption (VAT incl.) [k..]
☑ Cost of lighting energy consumption (VAT incl.) [k..]

Fig. 3. Actor's preferences for criteria: the case of the owner – Choice of relevant performance criteria.

- he chooses the background colour that identifies him in all windows generated by the software;
- he chooses the preferred monetary unit (Euro or the monetary unit of the country where the project is located).

For each criterion, he specifies:

- the maximum admissible critical value;
- an associated preference function, using the Promethee typology true ($\equiv$ usual) criterion, quasi-criterion, pseudo-criterion, etc. (Brans *et al.*, 1986) as illustrated on Fig. 4;
- thresholds P and Q of the preference function: if $P = 0$, this is a quasi-criterion, and if $P = Q = 0$, the criterion is true;
- weights he gives to the criteria: corresponding to the Promethee multicriteria approach, a weight is like a coefficient of the importance the actor attaches to each criterion (Schärlig, 1996). Each user allocates any null or positive weight to each criterion: the criterion receiving the highest weight is the most important one, while the criterion with the smallest weight is the less important one. The software so gives each criterion the relative weight it has in proportion with the sum of all the weights accorded to the criteria set. When an actor gives a null weight to a criterion, he expresses that he's completely indifferent to this criterion he considers not interesting at all. Weight allocating is a personal subjective matter depending on the value scale each actor feels on performance criteria.

3.3. *Actor's Scenarios and Questionnaires for Data Introduction*

An actor's scenario is a set of values the actor gives to the parameters he can understand and control. The introduced parameters are just necessary and sufficient to the preliminary performance estimates. At this stage of the project, prior to any drawing of the draft, the geometrical parameters replace the geometrical variables, which will be defined later.

In order to fit the technical capacity of the user, the collection of parameter preferred values characterising the project uses a questionnaire, organised on two levels:

- a semantic level, fitting the client's technical capacity; it helps the client specify his demands and requirements;
- a more technical level is proposed to the project author, who defines the preliminary characteristics of the project by answering no more than 60 questions.

The questionnaire is organised by items, i.e., thermal comfort, fenestration, solar aptitude, thermal characteristics of the envelope, equipment sophistication, etc.

For example, a screen is proposed to the client, asking him for the shape aspects he can define (upper part of Fig. 5). The same question, but on a more technical level, is proposed to the project author (lower part of Fig. 5). In order to facilitate user questioning, all answers are previously filled in with default values. The user may modify them as he chooses. In this way, the parameters necessary for other evaluations (corresponding to criteria considered as irrelevant) will not be introduced.

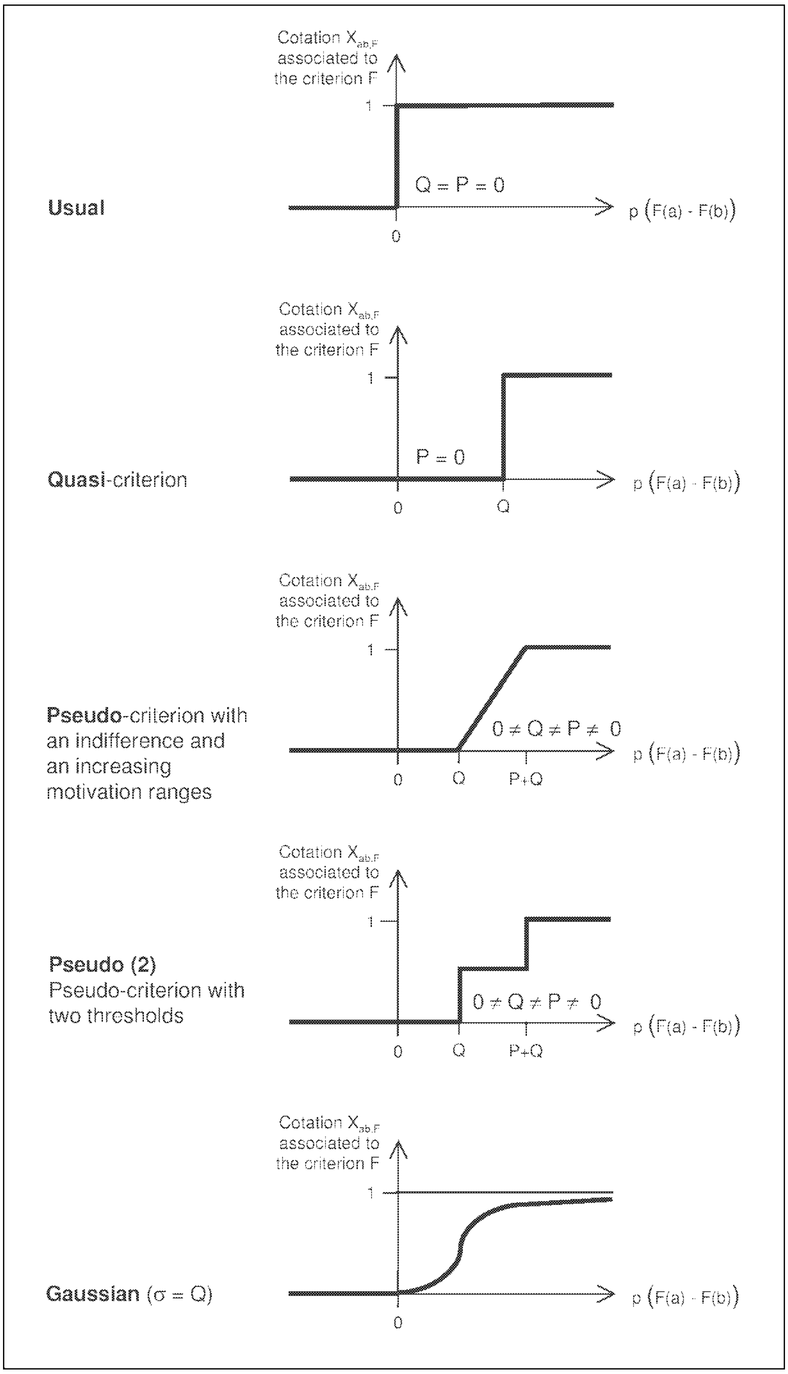
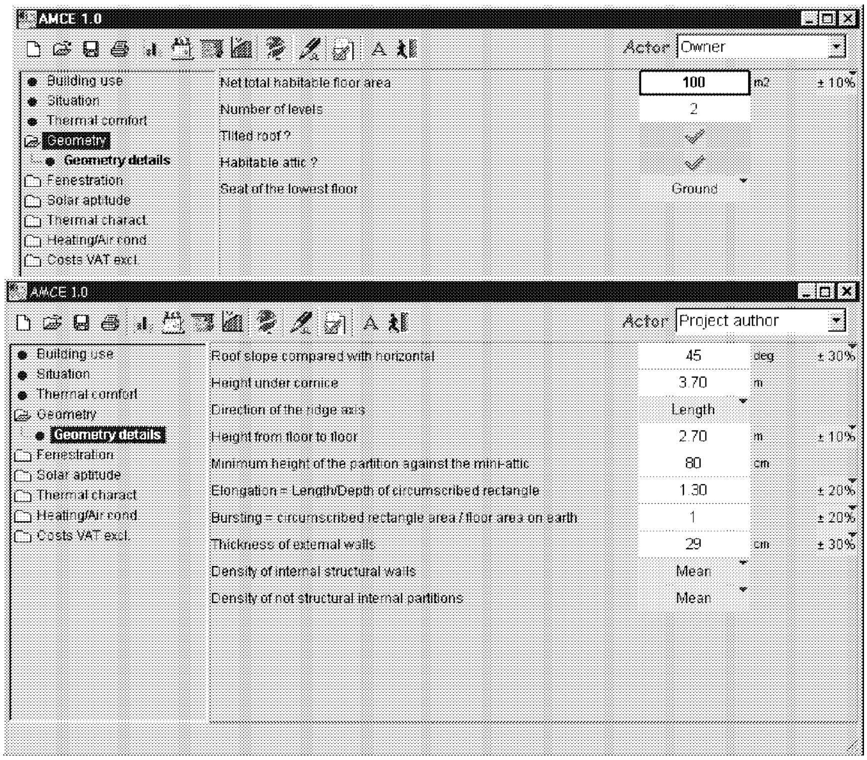


Fig. 4. Promethee preference functions.



Actor: Owner

Net total habitable floor area	100	m2	± 10%
Number of levels	2		
Tilted roof ?	✓		
Habitable attic ?	✓		
Seat of the lowest floor	Ground		

Actor: Project author

Roof slope compared with horizontal	45	deg	± 30%
Height under cornice	3.70	m	
Direction of the ridge axis	Length		
Height from floor to floor	2.70	m	± 10%
Minimum height of the partition against the mini-attic	80	cm	
Elongation = Length/Depth of circumscribed rectangle	1.30		± 20%
Bursting = circumscribed rectangle area / floor area on earth	1		± 20%
Thickness of external walls	29	cm	± 30%
Density of internal structural walls	Mean		
Density of not structural internal partitions	Mean		

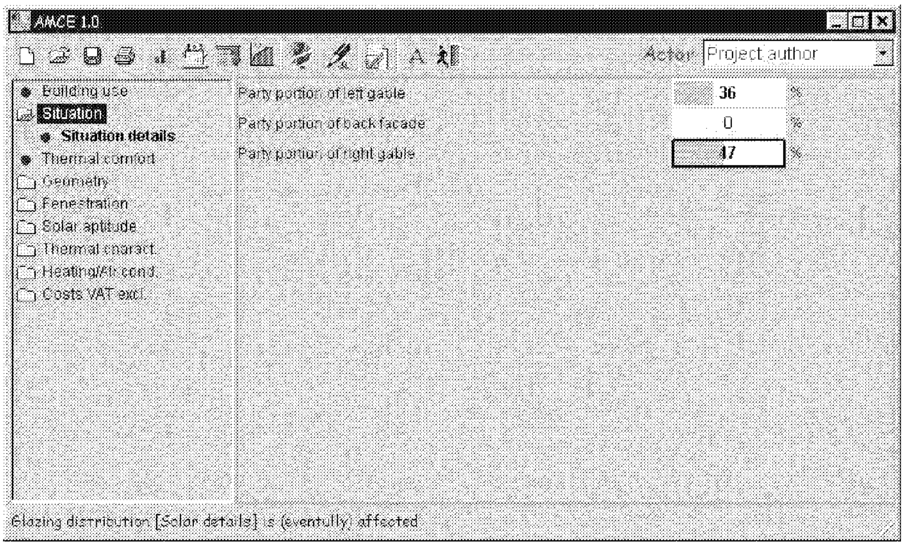
Fig. 5. Questionnaire proposed to the client (Geometry) and to the project author (Geometry: details).

Of course many parameters (and associated questions) may depend on other ones. For example, when specifying that the roof is a flat roof, the user has not to answer questions about attics or roof edge: these questions are suppressed from the questionnaire and are not asked. But, if a positive – and not nil – angle is still chosen for the roof slope, these questions appear again and must be asked if default values are not in accordance with actor's wishes.

A peculiar attention has been devoted to the mutual parameter consistency. The choices of fenestration and of shared external walls are an example. In the beginning of the questioning (see Fig. 6), the general situation of the project is asked to the user, concerning the party portion of the gables and of the back facade; the main facade is considered as having not any area shared with any other heated volume. When the user is modifying the party portions, a notice (see below part of Fig. 6) warns him that he must adapt the distribution of the glazed areas to the party portions he has modified.

The party portion default value is nil, which allows a uniform repartition of the glazed areas on all the facades (Fig. 7). The glazed areas are indifferently expressed in m^2 or in percentage of the project total glazed area. The user is allowed to adapt the repartition of the glazed areas in the "Solar details" management (see Fig. 8).

For strategic parameters, each actor specifies the accepted interval in which the parameter could vary. He so expresses his level of uncertainty and/or tolerance. Five different

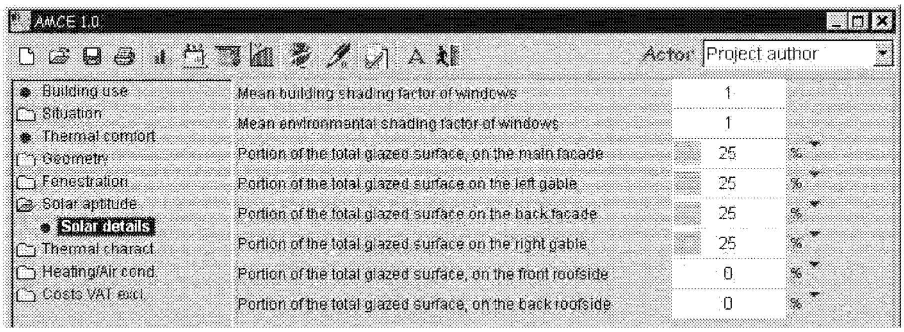


Actor: Project author

Party portion of left gable	36	%
Party portion of back facade	0	%
Party portion of right gable	17	%

Glazing distribution [Solar details] is (eventully) affected

Fig. 6. Party portions of gables and back facade.



Actor: Project author

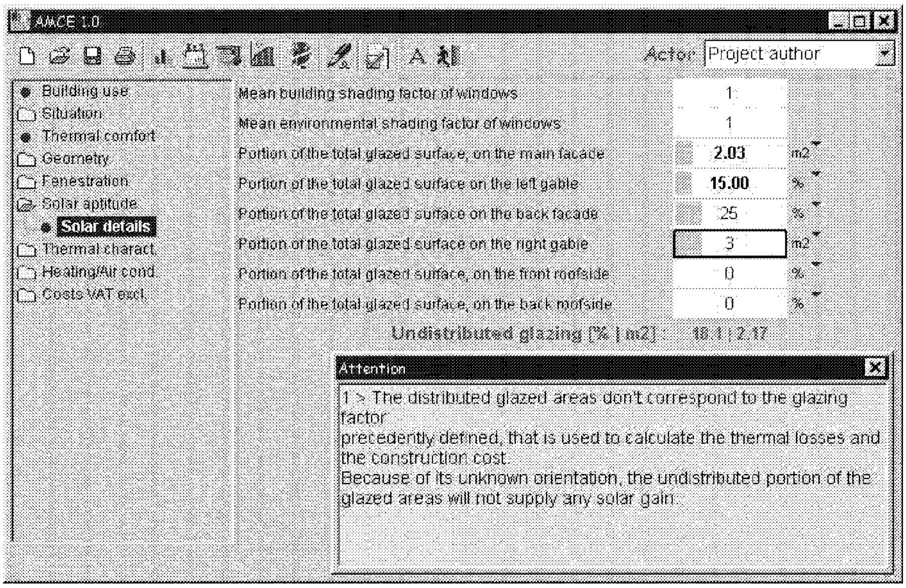
Mean building shading factor of windows	1	
Mean environmental shading factor of windows	1	
Portion of the total glazed surface, on the main facade	25	%
Portion of the total glazed surface on the left gable	25	%
Portion of the total glazed surface on the back facade	25	%
Portion of the total glazed surface on the right gable	25	%
Portion of the total glazed surface, on the front roofside	0	%
Portion of the total glazed surface, on the back roofside	0	%

Fig. 7. Default fenestration distribution.

levels of "tolerance" intervals are proposed to the actor, for his chosen value v:

level 1 : $v \pm 50\%v$; *level 2* : $v \pm 30\%v$; *level 3* : $v \pm 15\%v$;
level 4 : $v \pm 5\%v$; *level 5: no tolerance.*

The level 5 corresponds to a parameter that is prescribed by conditions outside the project and so cannot be changed by the design team. The actor thus chooses one tolerance interval level for each strategic parameter, according to his degree of certainty or/and his degree of requirement. Sometimes, one or both limits of his chosen interval is/are technically prohibited. In this case, the software introduces the largest technically feasible values within the preferred interval. This tolerance interval mechanism is crucial for further performance sensitivity analysis, and for the improvement step. If an actor enlarges intervals so that they are just limited by technical intervals, he may increase the



Mean building shading factor of windows 1
Mean environmental shading factor of windows 1
Portion of the total glazed surface, on the main facade 2.03 m2
Portion of the total glazed surface on the left gable 15.00 %
Portion of the total glazed surface on the back facade 25 %
Portion of the total glazed surface on the right gable 3 m2
Portion of the total glazed surface, on the front roofside 0 %
Portion of the total glazed surface, on the back roofside 0 %
Undistributed glazing [% | m2] : 18.1 | 2.17

1 > The distributed glazed areas don't correspond to the glazing factor
precedently defined, that is used to calculate the thermal losses and the construction cost.
Because of its unknown orientation, the undistributed portion of the glazed areas will not supply any solar gain.

Fig. 8. Correction of the fenestration distributed among the facades.

set of admissible scenarios, e.g., his feasible decision space. Each time he reduces his intervals, his decision space is reduced accordingly as well as the degree of improvement he may hope for in the next stage.

In the framework of MCDA methodology, the actor assesses a part of his preferences on scenarios through soft constraints. The remainder constitutes the minimal requirements he can impose on some performances.

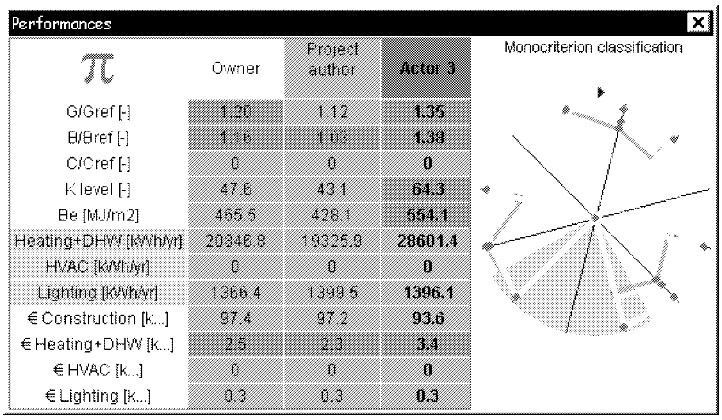
For each parameter, the following help will be provided on request, by the right click of the mouse:

- a more explicit definition of the parameter;
- values encountered in previous projects: the cultural approach of the project author is given here, consisting in a database of projects already executed by him, with associated parameter values.

3.4. *Displaying and Specifying Scenario Performances*

A specific window (see Fig. 9) lists the energy and cost performances obtained by all the scenarios defined by the actors (in bold: the actor currently using the software). Note that any actor can try more than one scenario.

In order to clearly display the satisfaction reached on the criteria specified by each actor, the background colour of each result cell is displayed: green when the performance is satisfactory for the actor and red, when it is not. In Fig. 9, for instance, the "Owner" is satisfied with all the performance values excepting that his scenario is unacceptable on: the French G/Gref and B/Bref coefficients; the cost of energy spent on "Heating+DHW".



	Owner	Project author	Actor 3
G/Gref [-]	1.20	1.12	**1.35**
B/Bref [-]	1.16	1.03	**1.38**
C/Cref [-]	0	0	**0**
K level [-]	47.6	43.1	**64.3**
Be [MJ/m2]	465.5	428.1	**554.1**
Heating+DHW [kWh/yr]	20846.8	19325.8	**28601.4**
HVAC [kWh/yr]	0	0	**0**
Lighting [kWh/yr]	1366.4	1399.5	**1396.1**
€ Construction [k...]	97.4	97.2	**93.6**
€ Heating+DHW [k...]	2.5	2.3	**3.4**
€ HVAC [k...]	0	0	**0**
€ Lighting [k...]	0.3	0.3	**0.3**

Fig. 9. Performance window.

The right column of Fig. 9 displays the relative classification of scenarios for each performance, in a monocriterion approach.

Fig. 10 presents a Promethee total pre-order of the scenarios: the owner's scenario is globally the best one, while the project author's one is less good and the Actor 3's scenario is the worse.

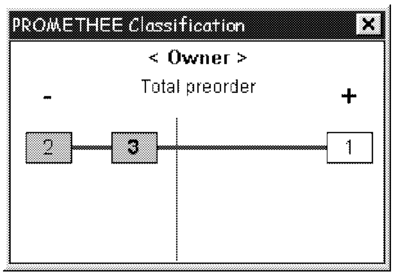


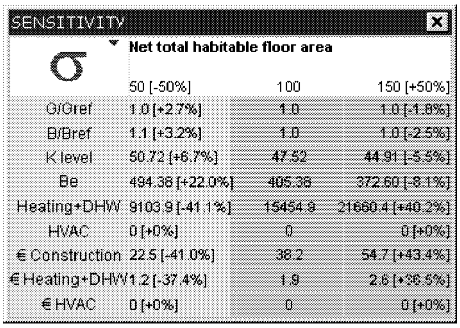
Fig. 10. Promethee total pre-order of the scenarios.

3.5. *Sensitivity Analysis Performed by AMCE*

The software calculates the performance variation for the criteria considered by the actors, according to the parameter variations, thus guiding the project author towards an improved solution.

The sensitivity of a chosen performance to the variation of one or two parameters can easily be obtained, so.

First, AMCE produces the σ performances for each chosen tolerance interval of the parameters and for each actor. For example, Fig. 11 displays, for each criterion, the performance interval produced by the interval of values (*level 1*: $v \pm 50\%v$) of the net total habitable floor area around its central value (100 m^2): the construction cost is 38.2 k€



σ	Net total habitable floor area 50 [-50%]	100	150 [+50%]
G/Gref	1.0 [+2.7%]	1.0	1.0 [-1.8%]
B/Bref	1.1 [+3.2%]	1.0	1.0 [-2.5%]
K level	50.72 [+6.7%]	47.52	44.91 [-5.5%]
Be	494.38 [+22.0%]	405.38	372.60 [-8.1%]
Heating+DHW	9103.9 [-41.1%]	15454.9	21660.4 [+40.2%]
HVAC	0 [+0%]	0	0 [+0%]
€ Construction	22.5 [-41.0%]	38.2	54.7 [+43.4%]
€ Heating+DHW	1.2 [-37.4%]	1.9	2.6 [+36.5%]
€ HVAC	0 [+0%]	0	0 [+0%]

Fig. 11. Window showing performance sensitivity to the variation of net total habitable floor area around its central value, 100 m2.

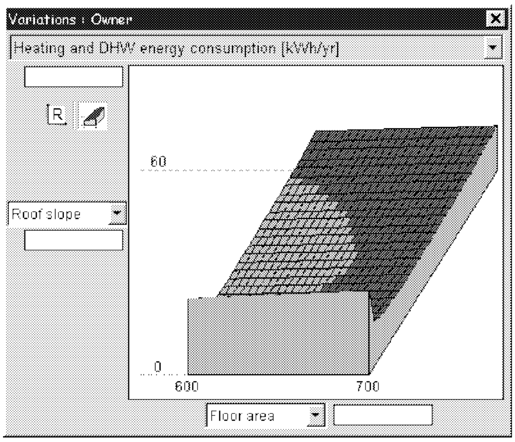
for 100 m^2; it increases 43.4% for a 50% increase in area, reaching 54.7 k€, while a decrease of 50 m^2 produces, *ceteris paribus*, a fall of 41% for a new amount of 22.5 k€. On this exemplary display we observe that some values are presented in a red cell: f.i., making variations of 50% of floor area becomes a prohibited scenario for the criteria B/Bref and still remains unsatisfactory relating to yearly "Heating+DHW" energy cost, of course.

Fig. 12 (3-D graph) and Fig. 13 (2-D graph) give the variation of the performance "Energy consumption (in kWh) for heating and domestic hot water", to both continuous and technically acceptable variations of the net total habitable floor area and of the roof slope together; all the other parameters are remaining unchanged at their decided central values. When the user clicks anywhere in the 2-D graph (Fig. 13), he can obtain the corresponding values of floor area and roof slope, with the performance obtained by this pair of values, all other scenario parameters remaining unchanged.

At the end of the feasibility study, before any drawing has been made, two possibilities exist:

- Actors know the certain existence of at least one solution, as defined by the satisfactory parameter scenario. In this favourable case, they also know the sensitivity of the performances to the different parameters. This information can be useful to arbitrate the divergent choices or possibly to improve design.
- Or they are not able to find a scenario leading to acceptable performances. In this case, the sensitivity analyses largely document the negotiation that must follow evidence of an empty set of solutions. Negotiation then attempts to relax the most sensible constraints.

Therefore, this first stage goes beyond a simple feasibility study, which would only show whether or not a solution to the architectural problem exists. Defining a set of solutions, this parametric approach also locates a scenario space where the preferred feasible choice exists. The combination of parameter intervals of validity/tolerance indeed defines a solution space, which respects the criteria considered as relevant. Definition of this solution space is essential for the strategy of future project improvement.

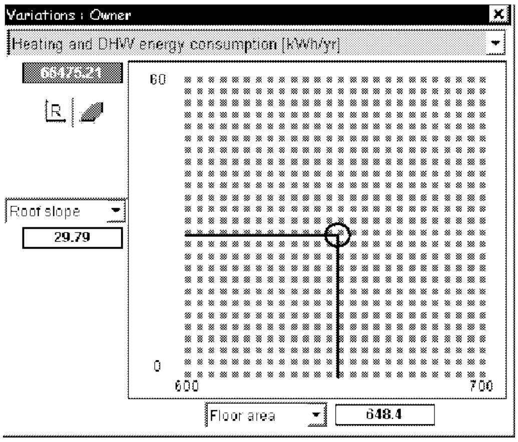

Variations : Owner

Heating and DHW energy consumption [kWh/yr]

Roof slope

Floor area

Fig. 12. Some performance sensitivity to the variations of the floor area and the roof slope (3-D graph).


Variations : Owner

Heating and DHW energy consumption [kWh/yr]

66475.21

Roof slope 29.79

Floor area 648.4

Fig. 13. Some performance sensitivity to the variations of the floor area and the roof slope (2-D graph).

3.6. *Monoactor Optimisation Procedure in Order to Reach the Optimal Scenario Corresponding to the Most Efficient Project*

With an optimisation procedure using a genetic algorithm, the software generates a random population of individuals. Each individual is so a combination of possible values of the strategic parameters among the 8 billion possible combinations resulting from the authorised values of the 13 (up to now) strategic parameters within varying interval the actor has previously chosen. Each "individual" is a 13 position vector where each position represents a strategic parameter.

The optimisation process is organised as follows:

1. A first population of individuals (which size is chosen by user) is randomly generated;

2. The fitness f_x of each individual x is calculated using:

   $$f_x = \frac{1}{d},$$

   where d is like a "weighted distance" to optimal performance in the 13 dimension space of solutions:

   $$d = \sqrt{\sum_{i=1}^{n} \left(\frac{P_i}{C_i} \cdot W_i\right)^2},$$

   with:

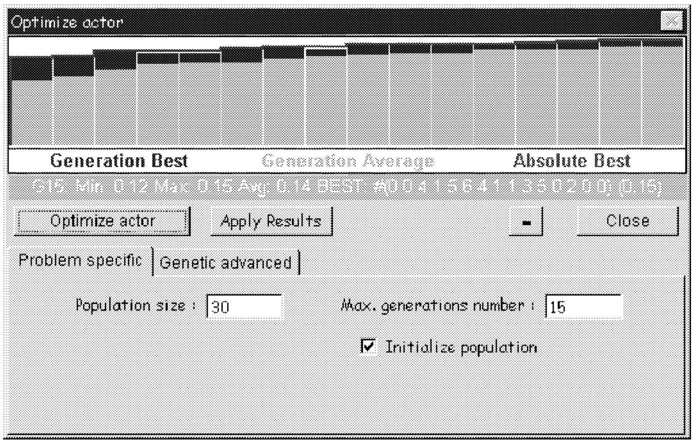
   - P_i = performance obtained relating to criterion i (all performances are to be minimised);
   - C_i = maximal authorised (or wished) value related to criterion i;
   - W_i = weight allocated to P_i;
   - n = number of criteria.

3. Statistical evaluations: maximum, minimum and mean fitnesses are calculated; if the maximum fitness is larger than the absolute best – obtained up to now – individual's fitness, the individual corresponding to the maximum fitness is saved as the absolute best one; otherwise the previous absolute best individual is kept;
4. Stop conditions: the optimisation process is stopped if maximum number of generations is reached or if the absolute best fitness increase over several generations is too small, so that the convergence is considered as obtained;
5. Population scaling: the population fitnesses are scaled in order to avoid any premature convergence, i.e., any local optimum;
6. Reproduction loop:

   - Selection procedure: fitnesses are distributed on a pie and the Russian roulette randomly selects a fitness, with a larger chance to come across a high fitness; the corresponding individual (parent) is selected by the software and a second one with the same way;
   - Croosover operator is applied to the selected pair of parents, giving children individuals;
   - Mutation operator is also applied to children individuals resulting from crossover;

A new population is so obtained, of new individuals. The process returns to Step 2 (fitness evaluation).

The software so finds the best combination of strategic parameter values (Fig. 14) that, in fact, generates the most efficient scenario whose performances are the best satisfactory in accordance with the actor's preferences.



G15: Min: 0.12 Max: 0.15 Avg: 0.14 BEST: #(0 0 4 1 5 6 4 1 1 3 5 0 2 0 0) (0.15)

Population size : 30

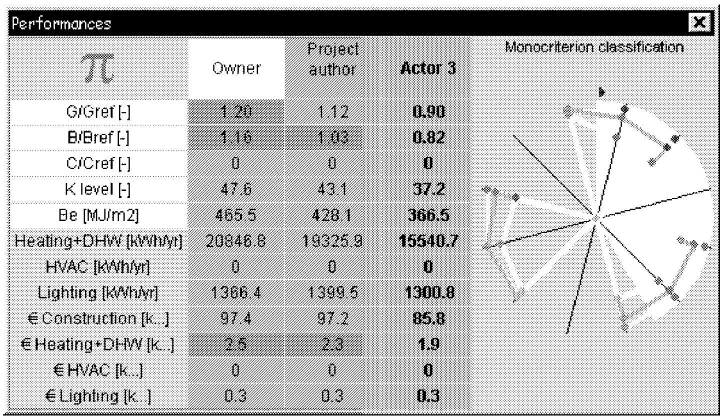
Max. generations number : 15

☑ Initialize population

Fig. 14. One-actor optimisation using a genetic algorithm.

In this monoactor optimisation, the actor's satisfaction is the convergence rule of the genetic algorithm.

On Fig. 9, the Actor 3's scenario gave worst performances when compared to the other ones. After the optimisation, the new Actor 3's performances (displayed on Fig. 15) have been largely improved. Not only G/Gref and B/Bref are now acceptable, but all this scenario performances are largely better than those obtained with the other scenarios, even for the "Heating+DHW" energy cost, remaining beyond the admissible value previously defined by Actor 3.



π	Owner	Project author	**Actor 3**
G/Gref [-]	1.20	1.12	**0.90**
B/Bref [-]	1.16	1.03	**0.82**
C/Cref [-]	0	0	**0**
K level [-]	47.6	43.1	**37.2**
Be [MJ/m2]	465.5	428.1	**366.5**
Heating+DHW [kWh/yr]	20846.8	19325.9	**15540.7**
HVAC [kWh/yr]	0	0	**0**
Lighting [kWh/yr]	1366.4	1399.5	**1300.8**
€ Construction [k...]	97.4	97.2	**85.8**
€ Heating+DHW [k...]	2.5	2.3	**1.9**
€ HVAC [k...]	0	0	**0**
€ Lighting [k...]	0.3	0.3	**0.3**

Fig. 15. Optimised performances of Actor 3's scenario.

3.7. *Multiple Actors Optimisation Procedure in Order to Reach the Most Preferred Compromise*

All the actors concerned by the project may to find their most preferred compromise, by using the multiple actors optimisation procedure. This optimisation routine is similar to the monoactor one, except of its convergence rule: the software must search for the scenario giving in the same time:

- as best performances as possible;
- most equal satisfaction of all the actors: when a project obtains good performances but gives actors too much different satisfactions, this project further life is threatened by the unsatisfied actor(s).

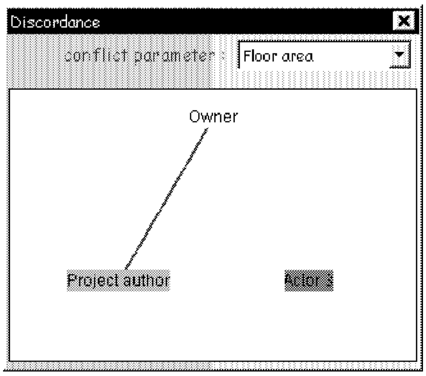
Before the procedure, a checking routine displays the parameter(s) conflicting with actors, i.e., the parameter(s) whose actors' authorised intervals have no intersection (Fig. 16). When it happens, one can say that the scenarios are not comparable, so that any preferred compromise does not exist. The conflict parameters must so be first negotiated between actors, before any optimisation.

In this way, the individual fitness f_x is differently defined than in the monoactor procedure:

$$f_x = \frac{1}{d_{\max}} \cdot \frac{1}{(d_{\max} - d_{\min})},$$

where $d_{\max}$ is the maximum value (the worst performance) encountered in d_{aj} values related to actor a_j and $d_{\min}$ the minimum d_{aj} value. The fitness optimisation has two parallel objectives, corresponding to the two terms in the f_x expression:

- maximising the performances is similar as minimising their maximum weighted distance ($d_{\max}$). Because no performance is nil and at least one mandatory regulation performance always remains, the denominator $d_{\max}$ may approach to 0, but cannot be nil.



conflict parameter : Floor area

Fig. 16. Display of conflict parameters (here the floor area) between the owner and the project author who's choice is similar to the Actor 3's one.

- equalising the actors' satisfactions is the same as minimising the difference between $d_{\max}$ and $d_{\min}$ values. The actors' satisfactions are equal when $d_{\max} = d_{\min}$ and the corresponding individual gives the parameter values of the preferred compromise.

4. Sketch Design: Drawing the First Draft and Performance Evaluation

The third stage of the decision process will allow a sketch design, but, at any time, the drawing of the first draft could be realised by the project author, using the *EsQUIsE* module, developed in LEMA (Leclercq, 1999).

EsQUIsE software is an experimental computer-based prototype interface for capturing and interpreting the architect's sketch, by locating its architectural concepts: border line, functional space and topology. The aim of this prototype is to compose a spatial semantic representation of the architectural project, in order to feed diverse computer architectural design evaluation routines and to serve as a tool with interface that complies to the designer's working technique. The EsQUIsE pen-based module performs the capture and the synthesis of the lines drawn on the digital tablet. These lines are drawn in black (opaque walls), in blue (glazed walls) or in magenta (comments) (see Fig. 17).

The project author names the functional spaces; on this basis, the programme fixes their characteristics necessary for the evaluations. For example, the default comfort temperature assigned to each occupied space is fixed according to its function as described in the captions: 18°C for the kitchen, 24°C for the bathroom, etc.; the user may change it if he prefers another value.

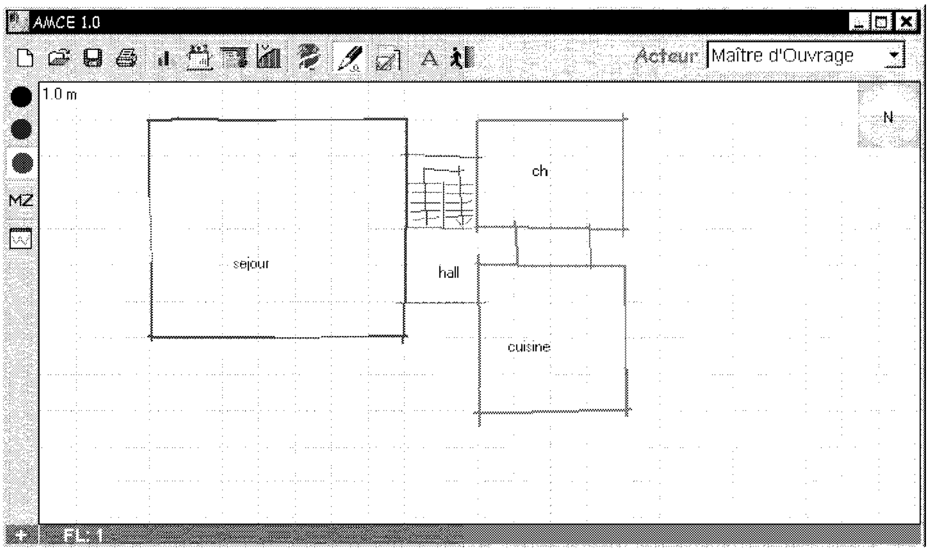


Fig. 17. Original sketch (ground floor) drawn on a digital tablet or with the mouse.

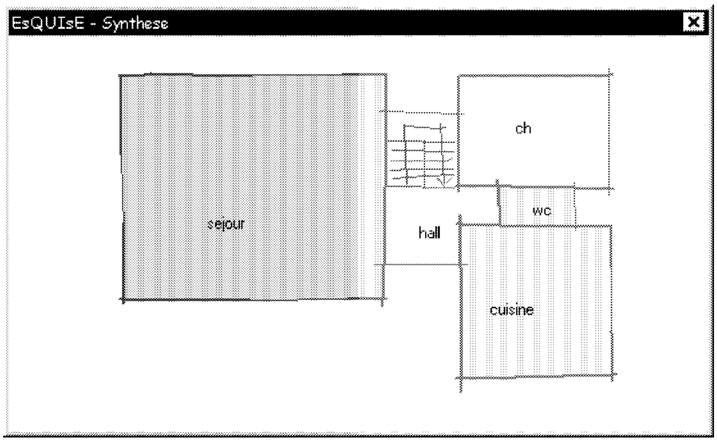


Fig. 18. Synthesised sketch of the ground floor.

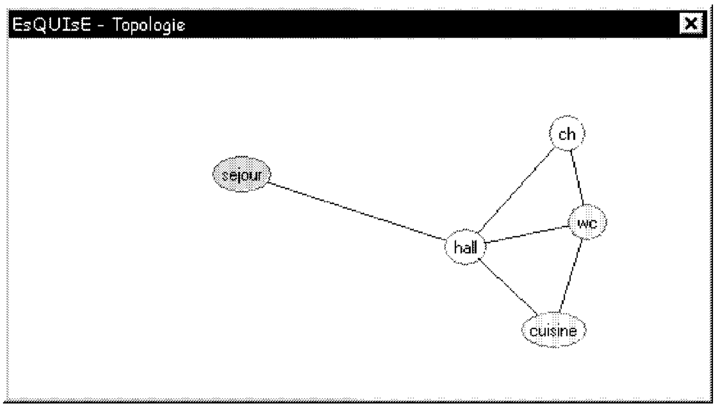


Fig. 19. Spaces topology of the ground floor.

The project author names the functional spaces; on this basis, the programme fixes their characteristics necessary for the evaluations. By studying the contacts between the synthesised lines, EsQUIsE materialises the spaces to be occupied (Fig. 18).

Several procedures then deduce the topological relationships of the described architectural project (see Fig. 19).

The advantage of using a man-machine interface based on the semantic analysis of an architectural sketch is that one is spared the fastidious measuring work of the architect's blueprint. Instead of the two or three days usually required to measure and encode, energy and cost performances are supplied directly after the drawing of the last line of the sketch. On the other hand, it avoids any accidentally wrong numerical values when input by human user.

This drawn support constitutes a preliminary basis for discussion with the client, whose understanding requires a graphic expression. This constitutes the only means of checking how well the project corresponds to his desiderata, including implicit ones (non-verbalised). This first response is already rich, particularly with regard to evaluations.

The application tested in the late stages of EsQUIsE is a classical module MZS (for **M**ulti**Z**one **S**tationary) also previously developed in LEMA: it makes the multizone evaluation of the building energy needs, taking internal and solar gains into account (see Fig. 20).

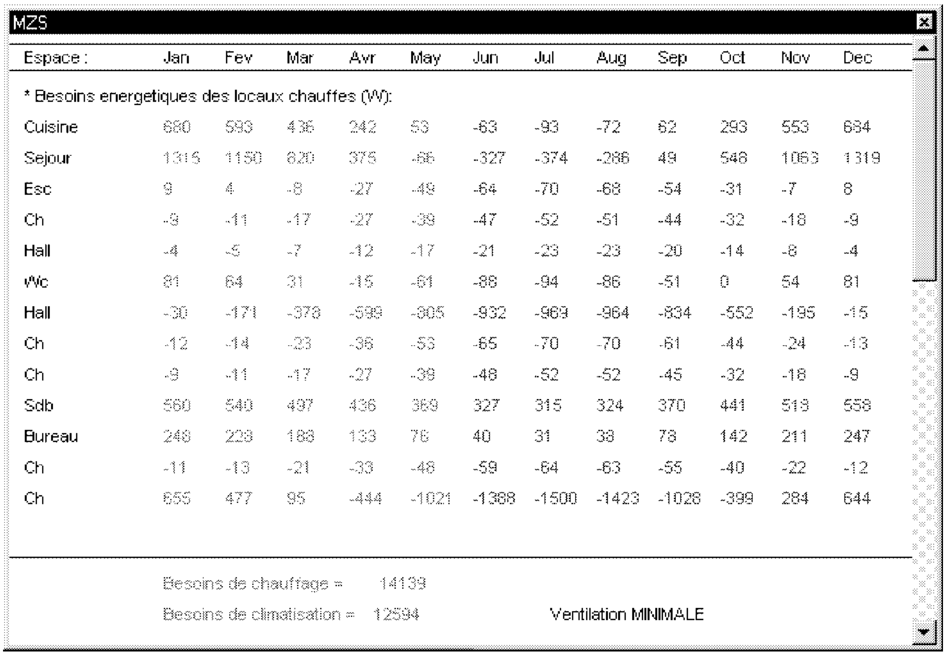
After the drawing of the draft by the project author, the user can go back to the parameter module, where geometrical data previously defined are replaced by the ones generated by the drawn sketch (Fig. 21). Other thermal or economical data of the questionnaire are unchanged.

The same evaluation routines check project performances of the drawn project, that are displayed in the performance window:

- either the performances are reached;
- or the performances are not reached. Any actor could try to satisfy each requested performance by using the parameter sensitivity analyses or the optimisation procedure. In the case of a conflict between reached and desired performances, a negotiation would be initiated, in order to refine objectives and parameter values.

The project author presents the draft to the building owner, who is now able to react and intervene on parameters and desired performance values.

Improvement (and/or optimisation) of the draft, by its iterative modification and/or by the drawing of new drafts, will take the procedure back to previous stage.



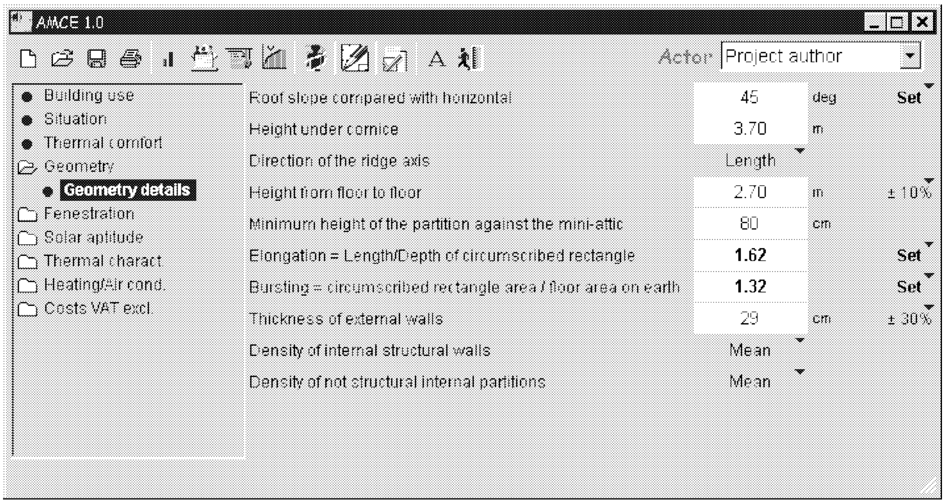
Espace :	Jan	Fev	Mar	Avr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
* Besoins energetiques des locaux chauffes (W):												
Cuisine	680	593	436	242	53	-63	-93	-72	62	293	553	684
Sejour	1315	1150	820	375	-66	-327	-374	-286	49	548	1063	1319
Esc	9	4	-8	-27	-49	-64	-70	-68	-54	-31	-7	8
Ch	-9	-11	-17	-27	-39	-47	-52	-51	-44	-32	-18	-9
Hall	-4	-5	-7	-12	-17	-21	-23	-23	-20	-14	-8	-4
Wc	81	64	31	-15	-61	-88	-94	-86	-51	0	54	81
Hall	-30	-171	-378	-599	-805	-932	-969	-964	-834	-552	-195	-15
Ch	-12	-14	-23	-36	-53	-65	-70	-70	-61	-44	-24	-13
Ch	-9	-11	-17	-27	-39	-48	-52	-52	-45	-32	-18	-9
Sdb	560	540	497	436	369	327	315	324	370	441	519	558
Bureau	248	223	183	133	76	40	31	38	78	142	211	247
Ch	-11	-13	-21	-33	-48	-59	-64	-63	-55	-40	-22	-12
Ch	655	477	95	-444	-1021	-1388	-1500	-1423	-1028	-399	284	644

Besoins de chauffage = 14139

Besoins de climatisation = 12594

Ventilation MINIMALE

Fig. 20. Monthly and yearly heating (and cooling) energy needs of the drawn sketch.



Actor: Project author

Roof slope compared with horizontal	45	deg	**Set**
Height under cornice	3.70	m	
Direction of the ridge axis	Length		
Height from floor to floor	2.70	m	± 10%
Minimum height of the partition against the mini-attic	80	cm	
Elongation = Length/Depth of circumscribed rectangle	**1.62**		**Set**
Bursting = circumscribed rectangle area / floor area on earth	**1.32**		**Set**
Thickness of external walls	29	cm	± 30%
Density of internal structural walls	Mean		
Density of not structural internal partitions	Mean		

Fig. 21. Geometrical data replaced by the ones resulting from the sketch drawn with the EsQUIsE module.

5. Continuation of the Project Design

The result of the feasibility stage is a sketch which parameters – accepted by the several actors – give the best performances. It circumscribes the most efficient choices related to the energy and cost performances of the future building.

It now constitutes the project basis to be used in the continuation of the design process during the *detailed design*, that falls under topics currently developed and commonly used in architecture.

6. Conclusion and Further Advances of the Sketch Design Tool

With respect to usual architectural practice, our new methodology tracks provide the following advantages:

- they alleviate the work load of the project author and increase energy and cost performances of the project;
- they supply a multiple criteria decision aid for elaboration and negotiation of a preferred compromise between the several actors;
- they give enhanced help to the client within an uneasy technical context, where his responsibility is increasing, especially regarding environmental regulations.

In conclusion, the final product will be used to interest more architects and help them in building energy performance, both a present and future ecological concern.

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Interaktyvių priemonių, skirtų pastato konstrukcijai pirmosiose architektūrinio projektavimo stadijose parinkti, daugiakriterinių ir grupinių sprendimų aspektai

Sleiman AZAR, Jean-Marie HAUGLUSTAINE

Studijoje nagrinėjamos daugiakriterinių sprendimų priėmimo procedūros, taikytinos pastato pradinėse architektūrinio projektavimo stadijose, kuomet yra parenkama didelė dalis galimų alternatyvų, įtakojančių pastato kainą ir eksploataciją. Projektų autoriai dažniausiai energetines sąnaudas vertina retai, skirdami didžiausią dėmesį kaštams. Straipsnyje nagrinėjamos interaktyvinės daugiakriterinių ir grupinio sprendimų priėmimo priemonės, įgalinančios pagerinti architektų darbą atsižvelgiant į klientų pageidavimus bei esamą teisinį reguliavimą. Projekto autoriai gali pasitelkti architektūrines priemones, užtikrinant klientams kainos, pastato gyvavimo, komforto bei funkcionalumo tikslus ir priimtinus energetinius bei ekologinius reikalavimus. Projektavimo technologija susideda iš dviejų nepriklausomų modulių. Prieš pradedant projektavimą, sudaromas klausimynas, atitinkantis kiekvieno dalyvio technines užduotis, kuriame pateikiamos nepriklausomos versijos, įvertinus kaštus bei energetines sąnaudas. Antrajame modulyje optimizavimo procedūroje genetiniu algoritmu nustatoma efektyviausia parametrų aibė ir ruošiama projektinė dokumentacija, atitinkanti lanksčiausią ir priimtiniausią kompromisą, pateikiant ją klientui suprantamu būdu. Atitinkama programinė įranga įgalina sudaryti sąmatas ir reikalingus brėžinius bei grafinę medžiagą. Projekto autoriai gali lanksčiai naudotis pirmuoju bloku parametrams patikslinti leistinų sprendimų erdvėje.