Programming and Assisted Sketching

Graphic and Parametric Integration in Architectural Design

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Abstract: In this paper, we present our latest research related to the concept of a sketch-interface. After describing our vision of computer assisted design and the conditions necessary for its effective implementation, an original data model is presented, which covers different levels of representation and is grounded in a database of implicit information. We then describe our software prototype, which exploits the potentials of the digital sketch, in order to demonstrate how our ideas are pertinent and the feasibility of three kinds of applications. In particular, we argue in favor of using an architectural software program in relation to the sketch within the same computer assisted environment at an early stage in the design process.

1. INTRODUCTION

Most software programs currently used in architectural practices inadequately cover the phases of architectural design. Historically speaking, they are above all intended for the production phases. That is, once the goals of the design have been almost entirely defined, these tools allow users to express how this production can be carried out (plans and construction materials) and their probable performance levels (cost, thermal behavior and stability). However, at this stage, everything has been decided. Indeed, the object has already been designed, yet the designer has received no assistance as far as initial decisions are concerned, and no support in terms of decision making strategies. Moreover, how could current software tools for architectural production possibly aid the reflections of a designer of an inhabited space? Most of these applications supply only a representation of the building's structural elements: the basis of their data model is mediocre, consisting only of the walls, floors and other technical or architectural features. In order to assist designers effectively in their creative work, it is necessary to use the same concepts and levels of representation as they do.

1.1 Conditions for Assistance

We believe that any software package conceived to assist architectural design must have two main characteristics. On the one hand, its model must be centered on the architectural spaces being designed, on the other, it must enable the user to combine different levels of abstraction.
The goal of the first condition is only to ensure that the foundations of the knowledge manipulated by the computer correspond to the concepts used by the designer. Clearly, the spaces created by the designer are above all functional, that is places destined to house several specific activities, which require particular spatial, physical and environmental conditions (e.g., appropriate temperature, air quality, acoustic characteristics, colors, lights). Any tool that does not integrate these concepts in its data structure cannot, in our opinion, pretend to play the role of an architectural design assistant, since it does not use the same model as the architect to represent its main object.
The second condition is linked to how well the concepts being manipulated are defined: because they are being designed, they become more or less abstract or concrete during the planning process. For example, the functions of a future building are located and arranged in units that are rather vague and incomplete in the beginning. Then, little by little, they crystallize into a geometric form that becomes more and more precise as the architectural plans are progressively drawn up (Figure 1).

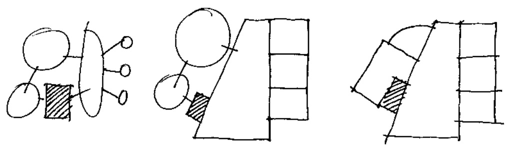


Figure 1. The evolution of an architectural sketch

Any software assistance tool must be capable of processing real architectural knowledge established using the same concepts of space and internal environment as the designer. At the same time, this software tool must effectively manage this knowledge with differentiated levels of information.

1.2 Assistance Media

Beyond this content, the mode of interaction between the designers and the tool assisting them must meet certain criteria to which we have already drawn attention through our discussion of architectural sketches (Leclercq, 1996). These criteria are inherent in the use of the sketch, which is the working method favored by professional architects. Though imprecise, vague, incomplete, and limited in its means of expression, the sketch is unquestionably the most popular mode of expression in the architectural design process. It is a means of simulation and a malleable raw material, which also creates a visible trace of the creative thinking process. In this way, the sketch can be considered as a reflection of a designer's cognitive work. It is a form of feedback for the designer: the model laid out on paper is not neutral, it reacts, strikes back, revolts against or conforms to the commands of the designer, who attempts to adapt it to the constraints of his or her project. In our model, the sketch is the means by which an important part of the designer's work can be captured.

1.3 Skills

Based on the analysis of 1600 professional sketch operations, we have already argued that it is possible to capture the main message contained in an architect's drawing. (Mathus, 1994). However, this potential is dependent upon two conditions:

1. There must be a common means of graphical expression that can be shared by all the designers concerned. In the area under consideration, we have observed that regardless of education (artistic, engineering), architectural style (functional, symbolic, organic, classic), and experience, all architects use a common, shared means of representation. It is important to note that our observations concern descriptive working sketches of the type exchanged between designers in a professional context. We are not considering artistic sketches intended for customers or for presenting the project to the public or to a jury, for example.
2. There must also be a large quantity of common implicit information, for within the architectural sketch the designer implements the figuration of basic concepts. Its economy of means makes it usable and preferable at an early stage of design, but at the same time limit its contribution to the management of secondary information from the designer. The designer considers this information as a body of implicit data, "which goes without saying," and enables the designer's collaborators to interpret effectively the global information summarized in the sketch.

We must add a third condition that any software package intended to assist design through sketches must respect. With its typical shortcomings of imprecision and incompleteness, the sketch represents a multi-level representational space. Some lines precisely denote the fine geometry of an architectural space that is already well defined in the designer's head. However, in the same drawing, a blob may appear: a vague, unclosed unit, recalling the presence of a space that has not been precisely defined, but that has already been characterized in terms of its function and the approximate area required (see Figure 1).

Yet it is exactly this lack of rigor inherent in the free-hand sketch, which seems like a fault when endeavoring to computerize the process, that makes the sketch such an interesting tool. In effect, free-hand drawing is the only means of expression that affords creative freedom. The level of abstraction it can attain guarantees access to:

- the spatial solutions, whether formal or functional, that the designer imagines while drawing them;
- the graphic ideas that emerge, whether intentionally or spontaneously, on the paper from the hand of the designer.

2. THE PROPOSED ARCHITECTURAL MODEL

We propose an architectural model that meets the three requirements elicited above, and which is thus capable of processing and interpreting a free-hand architectural representation. I shall now describe the basic principles of this architectural information model, about which you can find further information in (Leclercq, 1994).

2.1 Levels of Abstraction

Based on Rasmussen's research on the states of human knowledge (Rasmussen, 1990), we propose a three-level model of knowledge, represented schematically in Figure 2.

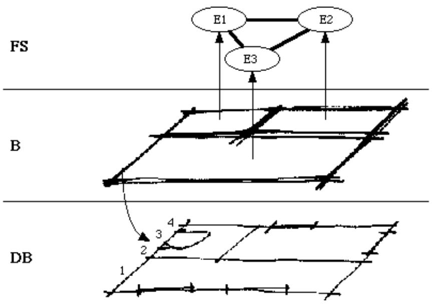


Figure 2. The three levels of knowledge in architectural design.

1. The first level of data representation can be called the " boundaries" (B). These stem from the graphic lines drawn by the designer in a working drawing , and represent the directly capturable traces of his or her thoughts. This representation is made up of architectural spaces, of inhabited areas, but is never represented as such. The designer establishes the boundaries, but at this stage, quite often it matters little to him or her how they will be made. What counts for now is the expression of spaces, the internal environments they are to contain, and the types of activities to take place within them.
2. In our model the spaces are concepts that have been deduced: they are generated based on the relational arrangements of the boundaries which cross or come together graphically. The second level is thus more abstract, and can be identified as that `which accomodates` space, associated with its functions and articulated in terms of its adjacency to other spaces. Independent of any metric or geometric constraint, this functional space (FS) network represents the essence of the plan in its relational and topological embodiment. It is therefore an architectural form of expression, which can be subjected to various forms of evaluation, such as a check concerning the building's accessibility. This form of architectural representation has a reciprocal relationship with the standard architectural representation by means of a plan, of which the sketch is an example. The sketch, therefore, represents an abstract expression of the architectural object being designed, in which a blob would fit in naturally.
3. On the other hand, at a more advanced stage when plans are more concrete, there is the level of detailed boundaries (DB), at which the lines representing the frontiers become more specialized. Characterized as doors, supporting walls or non-supporting internal walls, for example, the detailed boundaries are broken down into product models, the only way in which they are proposed in common CAD software programs. Therefore, this level leads toward a specialization of the elements in a

sketch, theoretically corresponding to the definitions of technical components found in CAD production software. Standard wall, column, beam, or concrete slab are identified and referenced at this stage using product catalogues, intended for take offs or other estimates: data which are extremely useful in the project phase that follows the design phase itself.

Beyond the fact that our model supplies this triple representation of the architectural object being designed, its main advantages are that the three levels are simultaneously produced and permanently linked.

– From the functional-space level, the designer can access a database of concrete cases and be assisted by functional or topological similarities in other designs.
– From the detailed boundaries level the designer can arrange the project at an advanced level of definition enabling direct access to the production phase of the project.
– By linking the topological diagram of spaces and the definitions of construction technologies at the level of detailed boundaries, certain evaluation factors until now inaccessible at the sketch phase become available to the designer, such as the estimation of energy performance levels and construction costs (as we shall see later in the presentation of the prototype).

2.2 Implicit Information

As I mentioned earlier, a sketch only reproduces the significant elements of the architectural project that it represents. It is not cluttered with obvious information that is assumed to be known or which will only be determined during the elaboration of the project. In effect, at this stage designers are not obliged or often do not wish to specify the semantic contents of everything they draw simply to reinforce their current design. In fact, they use a substratum of implicit data that we have described as three superposed layers (Figure 3).

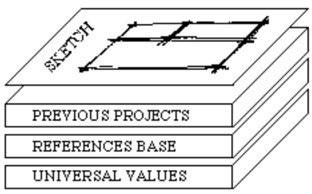


Figure 3. Layers of implicit information at the base of a sketch being drawn.

1. The first layer is a designer's own set of references, made up of previous designs, in which the designer or collaborators find everything that constitutes this designer's habits or personal preferences (e.g., usual ceiling height or sill height).
2. The second, more general layer covers the rules of good practice agreed upon by the community of professional architects to which the designer belongs. It includes the common rules, standards, and practices that any designer must observe in relation to national legislation, regional culture, or even local climate.
3. The third layer consists of universal references, such as material density values or thermal conduction coefficients for example.

Grounded in this collection of implicit data, the quickly sketched architectural drawing can be made more precise by an interpreting agent which, whenever necessary, performs searches in this hierarchical information base, from which the information needed to complete the architectural representation is taken. Thus organized, both in terms of prehension (abstraction/concretizing), and in terms of implicit information, our model is able to accommodate the sketched representation of an architectural object being designed. To continue my talk in more concrete terms, I shall now present our software prototype to demonstrate the feasibility of our propositions and how they operate.

3. THE DEMONSTRATION PROTOTYPE

The demonstration prototype, called EsQUIsE, is a geometrical interpreter of descriptive architectural sketches. For the time being the software packages only includes drawing procedures and lacks procedures for manipulating the objects once they have been drawn, and is therefore limited to the capture and interpretation of rough architectural sketches, and not yet to conceptual sketches. The sketch editing operations will be inspired by existing and very effective programs, such as Ideator (Kolli, Stuyver, Hennessey, Delft University of Technology, ND).

It is developed in a symbolic language, Common Lisp, and works using a Wacom digital sketchpad on all MacOS and Windows NT platforms.

It is made up of four basic modules (see Figure 4). First a graphic signal processing module, which synthesizes in real time the lines being drawn. Then there is a text recognition and semantic attribution feature for the captions in order to identify the function of each space. Finally, there are two procedures, carried out successively, to compose the spaces and deduce the topological relations in the architectural project being conceived.

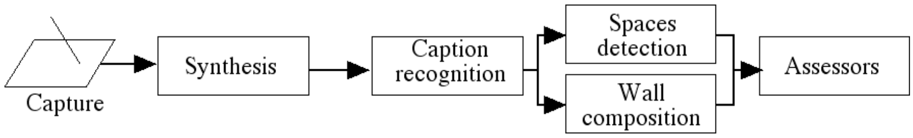


Figure 4. Procedural diagram.

The resulting architectural representation can then be sent to the usual software programs for assessing building performances. We shall now examine the role of each module in the order in which they come into action.

3.1 The capture module

The first module carries out the capture and synthesis of the lines drawn on the digital sketchpad. These can be in two colors, used to indicate the level of transparency of the walls: opaque or glazed. There is a third color available for non-significant additions to the sketch, for example shaded areas or the inclusion of furniture. (In time, we intend for this interface to evolve towards the concept of an "absent interface", to recreate the elementary, but immensely powerful, conditions of the paper sketchpad).
This capture module works at an acquisition frequency of at least 100 points per second, and processes a stream of information, whose size must imperatively be reduced in order for the process to be carried out in real time. A process of synthesis, made up of a set of successive filters, distills out the crucial information. The difficulty here is to reduce as much as possible the size of the representation of each line in terms of memory, while at the same time conserving a sufficiently reliable graphic synthesis of the original outline. These algorithms, whose objectives are obviously contradictory, are now capable of calculating a reliable synthesis of a line, in real time, using the equivalent of 15 % of the initial coordinate flow transmitted by the digital sketchpad.

3.2 The caption extraction module

Before the representations of the spaces are composed, a second module identifies and recognizes the functions of the spaces by means of the captions included in the sketch. These captions are necessary for establishing the architectural model described above, to be composed on the basis of the workings of the sketched plan. The technique, used in EsQUIsE since 1997, is based on the possibilities provided by the line synthesis module described above. Each line is decomposed into successive segments, whose orientations are coded in octants. Each line is thus translated in to a chain of concatenated codes, which can easily be compared with typical codes stored in a character base. We should mention that Park and Gero uses the same technique for the categorisation of shapes in its work on the application of the genetic approach to the composition of architectural plans (Park & Gero, 2000).

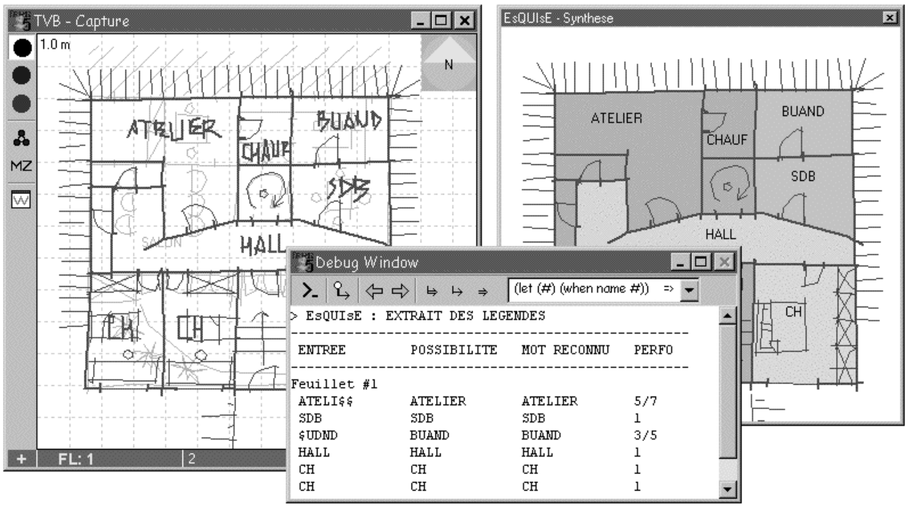


Figure 5. The original sketch, drawn on the digital sketchpad, the extraction of the captions, and the synthesized sketch.

This character recognition technique gives access to word recognition by means of a specific dictionary, which, in keeping with our proposal (figure 3), is located in the second layer of implicit data. Because of this limited dictionary, caption identification is very effective, since it is stable and gives performance levels equivalent to human performances. Thanks to this caption identification module, the prototype is able to name the different functional-spaces, and to link them to the characteristics usually associated with such spaces, such as the recommended temperature or noise level, which are also extracted from the database of implicit information.

3.3 Outline determination

By examining the points of contact of the synthesized lines, including the boundaries EsQUIsE can deduce the spaces demarcated by these lines.
These implementation procedures are fairly standard in the field of traditional computer graphics, where they are used in the techniques of outline determination in Boolean operations applied to coplanar polygons. The difficulty we encounter in our case is the imprecision inherent in an architectural sketch. In particular, we carried out a great deal of work on how

to define the ends of the hand-drawn line, which are always imperfect due to being interrupted, unfinished or overlapping. We therefore defined new procedures, called fuzzy computer graphics, able to continue or interrupt the dynamic movement of the line by processing error and proximity coefficients.
By overcoming this imprecision - though without correcting it, since the creative power of the sketch depends entirely on its unfinished nature – EsQUIsE can compose the second level of the architectural model, the more abstract level of functional-spaces. In addition, it can provide the characteristics of the boundaries between the functional-spaces. The size and orientation of each wall are easily located in the sketch. These metric data are then complemented by technological information, also from the implicit information database. Without any involvement of the designer, an interpreting agent itself selects the most appropriate type of construction technology. This selection is carried out by means of the internal environments separated off by each wall. These internal environments are identified from the functions determined by the caption recognition module. For example, between a bedroom and its adjacent bathroom, EsQUIsE chooses a wall that is sufficiently thick to provide soundproofing, and a wall covering that is impermeable to water vapor.

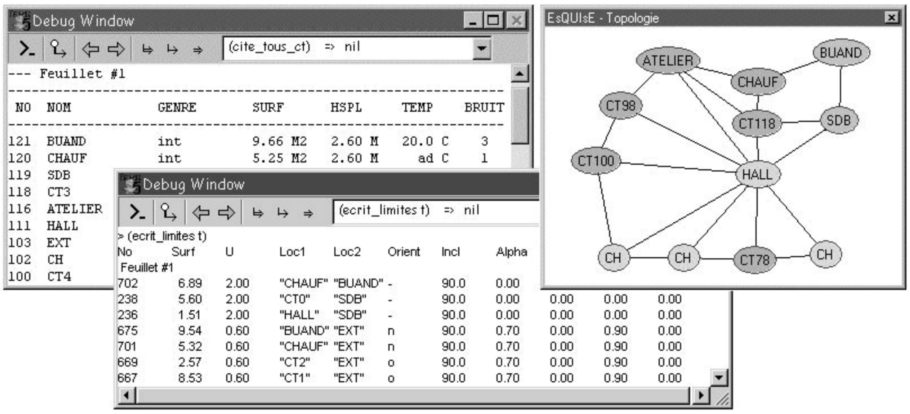


Figure 6. List and topology of the spaces and walls, together with deduced characteristics.

4. APPLICATIONS

The first application of EsQUIsE consists in generating, still in real time, a three-dimensional model of the layout corresponding to the sketch that has been drawn. Figure 7 gives a visual impression of the virtual scene available to the designer along with his or her digital diagram. This model is made up in Quickdraw3D, under MacOS, and can be manipulated as if it were a cardboard model. It is built up directly from the lines drawn in the sketchpad, whose 2D sketches are taken from their respective pages. The designer can examine this virtual object as he or she wishes, from the outside, by rotating it, or from the inside, wandering through it so as to perceive its spatial qualities. Any modification to the various components of the sketch is, of course, automatically reflected in changes to the model.

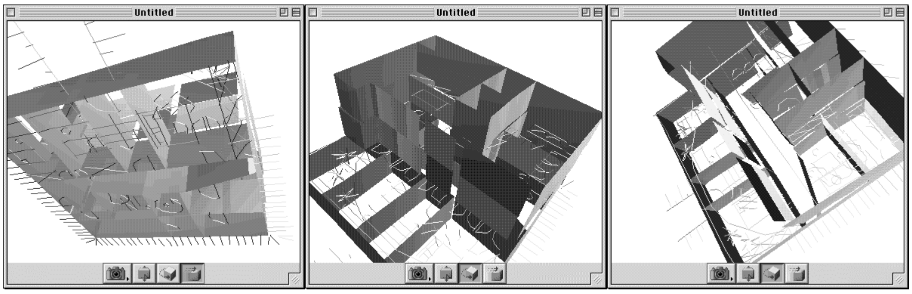
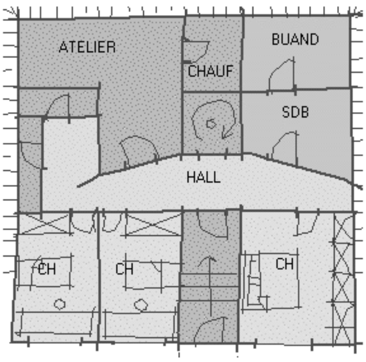
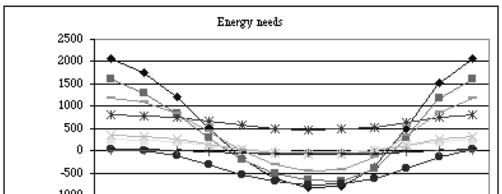


Figure 7. Manipulation of the virtual model

The second application of EsQUIsE consists of an evaluation of the energy needs of the architectural project. With a complete architectural representation of the sketched building now at its disposal, our prototype can submit it to a variety of different assessment processes. The results of these estimates each correspond to a forecast performance for the future building, which makes them very useful indicators for the design process. One application, called MZS, tested since 1998 downstream of EsQUIsE, is a conventional multi-zone evaluation module for the energy needs of a building.





	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bureau	2065	1754	1207	528	-174	-632	-814	-794	-359	495	1521	2068
Salon	1604	1301	829	305	-200	-523	-659	-688	-391	295	1169	1623
Cuisine	254	238	195	128	47	-9	-32	-25	24	105	197	249
Buand	339	316	255	156	36	-48	-85	-77	-6	114	252	331
Sdb	804	786	738	661	568	503	473	478	532	627	736	798
Hall	41	-1	-116	-302	-530	-690	-764	-754	-622	-393	-128	26
Ch	18	14	3	-16	-39	-56	-64	-63	-50	-27	1	17

Figure 8. – The energy needs of the sketched project are evaluated in an instant.

From the surface area and orientation of each window, MZS estimates the amount of sunshine likely to fall at each point and balances out the heating or air-conditioning requirements of the entire building, seen as a three-dimensional network of points. This method of calculating energy needs has been known for a long time, but its application in the context presented here demonstrates the advantage of our machine-user interface based on the use of the architectural sketch. Without the EsQUIsE prototype, the assessment shown in Figure 8 would require a great deal of tedious measurement and encoding of the building. With EsQUIsE, the building's energy performances are provided in a matter of a few seconds after the last line of the sketch has been drawn.

4.1 The Parametric Approach to Architectural Design

4.1.1 Definition of Constraints and Objectives

When the design process is examined (Gero and Neill, 1998), (Leclercq and Locus, 2000), we notice that before even drafting a first sketch to solve a given problem, the designer should first work out his or her domain of exploration. In Figure 9, this first phase is identified as that of the Definition of Constraints and Objectives.
Five sources of constraints, objectives, indications and inspiration can generally be identified: the client, the user, the site, the administrative authorities and the design team itself.

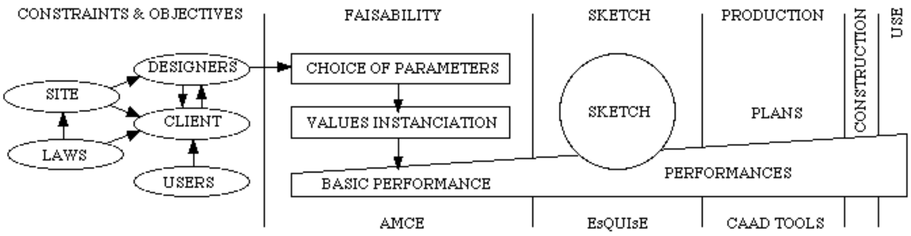


Figure 9. Structure of the parametric approach and a sketch.

Generally, constraints are integrated through a series of phases of negotiation, during which clients and designers refine their points of view and mutually expand their understanding of the problem. In this way, they progressively determine the outlines of the sub-space of potential solutions. In doing this, they prepare for the second stage in the design process by designating the determining parameters of the future project.

4.1.2 Feasibility Assessment

The second phase in the programming consists in assessing the existence and then the size of the sub-space of solutions. This step is very often neglected, especially in small or medium-size projects. But the issue of posing the question of feasibility appears to be crucially important at this stage in the process. There are two reasons for this:

- it forces the clients and designers to cover the full extent of the problem, and especially to characterize it by identifying its critical parameters;
- it enables them to progress towards the drafting of a solution with at least a minimal guarantee of a successful outcome.

However, it is clear that many architects – sometimes through incompetence, often through their eagerness to get started on the creative phase of their work – postpone this initial feasibility assessment step until after they have drawn their sketch. In so doing, they work with the graphic expression of their proposed solution, convincing the client and themselves that the process is operating smoothly. The feasibility assessment phase is tacked on after this cursory draft project Any feasibility test that turns out negative leads the designers into a phase of corrective engineering, during which the appropriateness of the proposed architectural solution is no longer called into question.

The next step in the feasibility assessment phase consists in assigning a value for each parameter that has been judged to be critical in the previous step. Any building can be defined according to four main sets of criteria: architectural expression, constructive principles, technologies of the building envelope, and functionalities. Instantiation of the related parameters, even when carried out fairly approximately, gives, by means of various simulations, a rough estimate of the crucial performance levels of the future building. Assessing these performance levels provides the answer to two questions concerning the above-mentioned sources: (1) thus defined, is the project feasible (i.e. will it meet all the external constraints)? And (2) is the project acceptable (i.e. will it satisfy all the internal objectives)?

With this enhanced understanding of the theoretical performance levels of their building, the designers can now start on the truly creative part of their work. Guided and supported by the predefined boundaries of the sub-space of solutions, their ideas can be more effectively formalized by means of the sketch than if the preliminary feasibility study had not taken place.

4.1.3 Illustration

To illustrate the potential benefits of this complementarity between the parametric approach and the architectural sketch, we shall examine the first results of studies carried out at the LEMA-ULg by our colleagues J-M. Hauglustaine and S. Azar, within the framework of a research project commissioned by EDF (Electricité de France), entitled AMCE, Aided Method for the Conception of the building Envelope (Hauglustaine, 2000). This research team developed a software application that uses the Parametric Approach and connected it up with EsQUIsE. In concrete terms, the AMCE parametric interface presents a set of different tables in which each "source" enters his or her constraints. Figure 10 gives an example of the definition of the simplified geometry of a building as seen, on the one hand, by the future owner and, on the other hand, by the architect. It is clear that the level of detail chosen by the owner differs very obviously from that used by the architect.

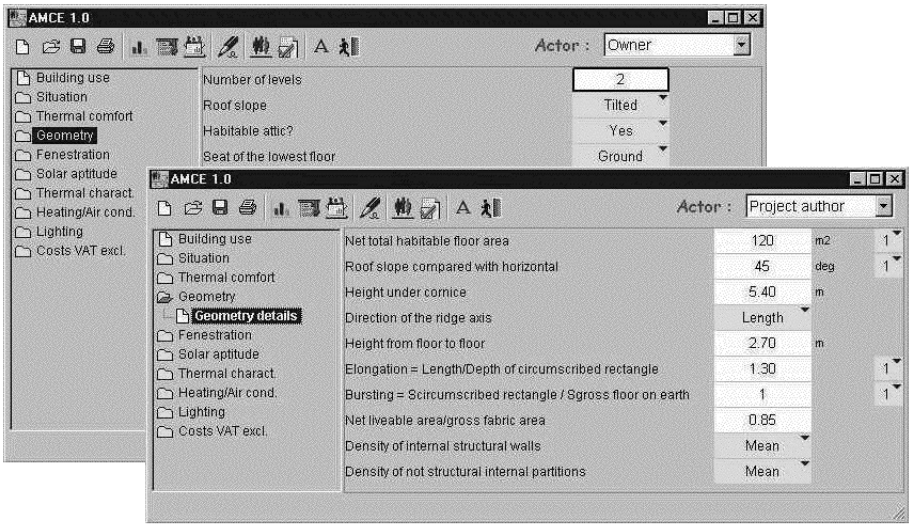


Figure 10. Geometrical constraints, as expressed first by the owner, then by the designer.

The introduction of parameters is not limited merely to assigning numerical values to them. The interface also enables the user to employ descriptive terms, couched in natural language, in order to specify the margin of possible evolution of the project. For example, the architect can express the wish that the number of walls should be "medium", thus indicating that he or she will neither be working on an open-plan design nor on a plan with too many juxtaposed internal spaces. This preliminary definition of the parameters covers all the normal domains of architectural design: use, location, thermal comfort, geometry, wall technology, heating, ventilation, lighting and economic considerations (62 parameters are now covered by the application). In the case of AMCE these are all related to EDF's particular requirements regarding the external envelope of the building. At this stage, the designer can embark upon the creative process using the digital sketchpad provided by EsQUIsE (see Figures 5, 6 and 7). At any moment during the design process, he or she can check the performance levels of his or her model according to the interpretation derived from it by the software package. In the context of AMCE, these performance levels are presented with regard to the preferences of all the "sources" at the same time.

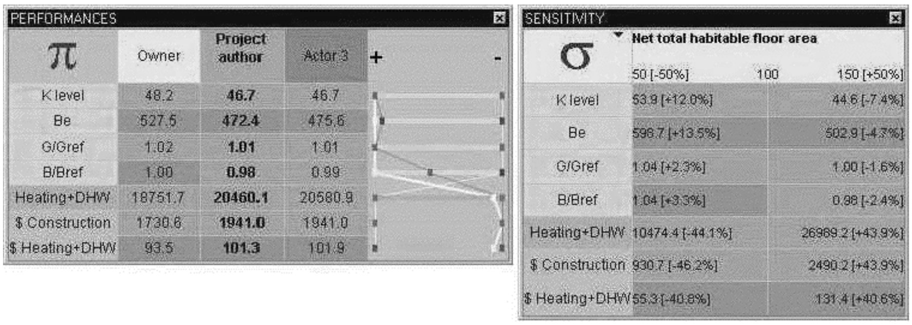


Figure 11. Performance levels expressed with regard to each "source" and of performance sensitivity.

Figure 11 (left), for example, gives the regulation energy performance levels (K, Be, G, and B) of the first sketch, together with building and operating costs. It shows that the building sketched by the project designer (middle column) gives better energy performance levels than those based on the interpretation of the requirements of the future owner. On the other hand, the construction and operating costs would be considerably higher than the original targets. In this example, therefore, the sketch needs to be modified in order to make it correspond better with the desired performance levels.

Finally, a results analysis module evaluates the sensitivity of the results with regard to any of the parameters considered in the programming phase. Figure 11 (right), for example, shows the impact on the different performance levels of a modification to the net habitable floor area, leaving all other parameters unchanged. In particular, it shows that a reduction in habitable area would make it possible to satisfy the economic constraints without excessively marring the thermal characteristics of the building envelope.

Progressively calibrated in this way by the designer, the architectural draft project can quickly be presented to the different parties involved, with the guarantee that the future performance levels of the building project will, as far as possible, be satisfactory to them all.

5. CONCLUSION AND FUTURE PROSPECTS

I have just described two complementary approaches of interest to the first stage of the architectural design process: (1) a parametric approach, which concerns the expression of constraints, objectives, and the feasibility of designing a future building (the AMCE research program); (2) a graphic approach, which because of the flexibility of its fuzzy expression opens up possibilities for creative exploration while respecting the working methodology proper to architects (the EsQUIsE program). I have explained the interest of linking these two approaches and showed, through the results obtained from the two software programs, how the quality of the designer's work can be improved, and in addition the increased satisfaction for the project sponsor and the other individuals taking part in the creation of the building. A designer can work in a solution field that is *a priori* compatible with that of his or her counterparts. A designer's proposition can be completed with greater freedom thanks to the sketch-interface software tool, which reproduces typical free-hand working conditions and assists in project elaboration through cross-references from a pertinent implicit knowledge database, generated from the parametric definition of constraints and objectives.

Developments in the EsQUIsE research program scheduled for 2001 concern first of all the extension of the notion of a sketch to include the generation of three dimensional volumes from working drawings other than superposed plans: sections and elevations must be integrated in order to perfect the architectural representation. Second, we will attempt to apply our data model to the implicit formulation of requests during design with a database of specific cases. Faced with the numerous propositions of architectural case data bases that are unusable, because they lack an adequate interface, we believe that EsQUIsE can provide the key for implementing the theories that have been developed in this area since the 90's.

The AMCE research program will close in May 2001 with an application test in an architectural firm. An estimate of its potential contribution will be established based on the use of this prototype in the professional world. Unavailable today, the results from these tests will be announced in July during the talks at CAAD Futures 2001.

By formalizing the architectural sketch in a useable and concrete manner, and thus displacing it from paper to a virtual medium, we will open up a new field of use for the sketch. Thanks to their capacity to recognize the roles and relationships of and between the components in an architect's sketch, our prototypes provide a design environment that gives active assistance at an early stage of architectural design, thus assuring that the process will be a coherent and creative one.

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