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INFERENTIAL MECHANISMS TO BE EMPLOYED IN CAAD: THE CASTORP SYSTEM

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Abstract

The paper presents an approach to the problems of architectural design aided by Artificial Intelligence techniques that can solve the difficulties related to combinatorial explosion, often encountered in the past.
Three expert systems, dubbed "reasoners", capable of some elementary design work and a hypothesis for their interaction have been developed.
Reasoner A has an view of "analogical" view of space. A notion of conflict, managed by means of fuzzy logic, has been introduced. It corresponds in an intuitive and straightforward fashion, to the common notion of conflict or contradiction in real space as a consequence of improper overlapping of actual physical objects or of their functional pertinence.
Reasoner B works on formalized models of building objects. It designs new patterns from given patterns taken as defaults.
Reasoner C picks up from an archive of patterns the one which best suits a list of given goals. Design is the result of interaction between the three reasoners.
Finally, the proposed schema raises questions about formal structures ("images") and about the nature of cultural-linked options ("memory") on which some preliminary considerations are made.
Prototypes of the reasoners are operating at the Istituto di Edilizia of the University of Ancona, Italy.

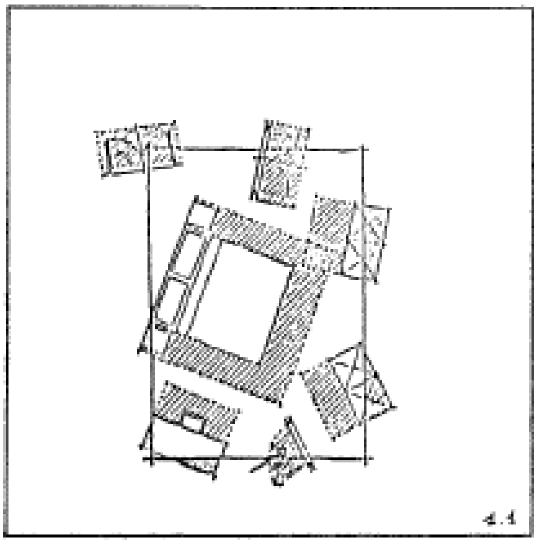
0. FOREWORD

In [4]a preliminary hypothesis for the implementation of an electronic simulator (expert system) for building design was presented. In that context a series of "reasoners" has been proposed capable of accomplishing operations that are typical of building design. The term reasoner (preferred to "expert system", more currently used) is meant as a procedure capable of some modes of reasoning applied to a few elementary and strictly-defined operations normally used in architectural design. We shall not discuss here the cultural and epistemological implications that led us to analyse architectural design in terms of "network of reasoners".
It is supposed that reasoners take into consideration a list of work hypotheses similar to those normally considered by architects, were they aware of them or not. Computer science employs the notion of "default"

for an assumption which is held (a priori) acceptable until it is shown unacceptable, and then modified. Our reasoners assume as a default a structured set of positions, points of view and building objects (in the scale required by the building operation carried out by the reasoner in question). That is tantamount to saying that reasoners possess a "culture" they have to use and modify in order to solve the specific problems they are faced with.
Three reasoners have already been thoroughly tested. Reasoner "A" tackles the problem of the placing of objects within a predefined space [8] It has an "analogical" representation of space and employs "fuzzy logic" [7] in order to represent the (qualitative) knowledge humans use when they functionally and morphologically analyse elementary spaces and their relationships.
Reasoner "B" presupposes that the computer has a database of structures representing building plans (our example is that of the dwelling). The computer starts from any of these structures and then it adopts a strategy for the deformations to be carried out on the object initially taken as default, in order to attain a solution consistent with project specifications. [5,12].
It is a precondition of this approach that building objects can be effectively and reliably represented in a formalised fashion. In [3] we developed a theory for the formalized representation of building objects which used the notion of matroid and can be helpful for our purpose.
Reasoner "C" questions the options reasoner B took as defaults; in other words, its task is to point to the element on which reasoner B is to accomplish further reflections within the inventory of all possible elements. Reasoner C features the possibility of applying formal and aesthetic criteria to future developments of our research work. From this very stage, however, it has not been excluded that the paradigms proposed by reasoner C are "educated" and significant in terms of architectural criticism. At the time of writing, reasoner C only partially develops reflections of this kind [9]: it is given a set of project specifications as inputs that it associates, where possible, to the paradigm elements' contradictory and diversified performance features. Such assessment is accomplished using a multiobjective approach.

1. Reasoner A: dimensioning spatial elements

Let us turn to the definition of some qualitative aspects of a mode of reasoning (*understandable by the computer*) that, known the definition of "elementary activity-space" of each spatial element, could allow us to move to the definition of "global activity-space" [13] of the same space elements. In other words, the passage is from the space occupied by furniture and their functional pertinences to the dimensioning, of their container. We assume it as known the notion of "segment" defined as a set of graphic primitives as is usual in computer graphics. Let us remind you that you that in computer graphics the notion of segment is an elementary one, since images result from a collection of suitably structured and processed segments. Such notion seems to suitably represent *our* elementary data. "Elementary activity- spaces", with their dialectic between space actually occupied and functional pertinence, can indeed be represented by suitable "segments" in which it is possible to distinguish the different nature of the two spaces



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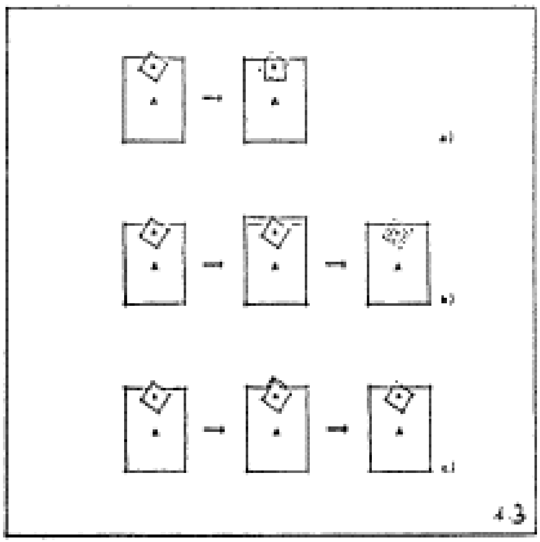

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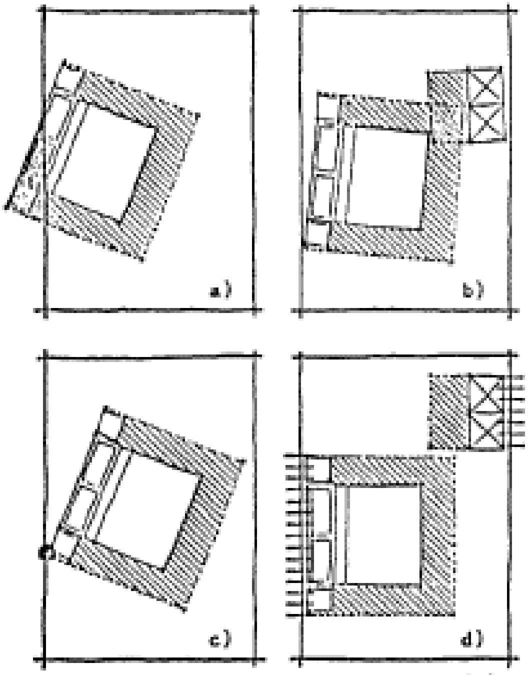

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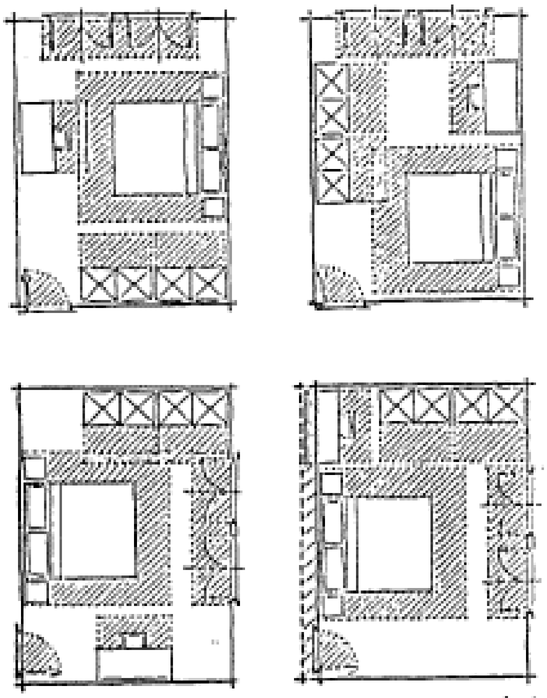

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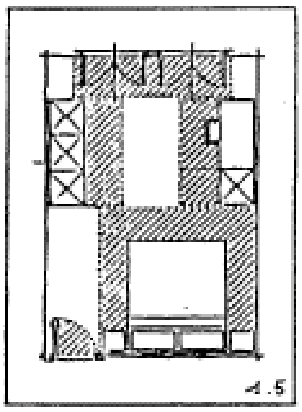

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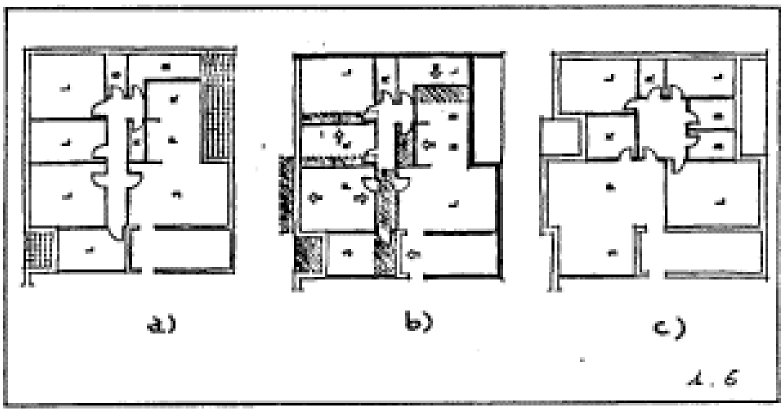

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kinds of spaces. Obviously, spaces occupied by fittings cannot overlap, whereas functional pertinences allow different levels of interference. Both from a conceptual and an operational point of view, "fuzzy set" logic seems to adequately represent the necessary shading of constraints [6].

Let us go back to the representation of the passage from elementary to global "activity-spaces". Let us suppose we have a list of furnishings and fittings together with the pertinence spaces required for their usage and correct functioning, as suggested by ergonomic techniques.

At the beginning of our discussion we assume, as a default, a (global) space perfectly defined in its dimensions and represented by means of a segment. Since its dimensions are totally arbitrary and since we have no criterion in which to place our furnishing (the space should be seen as a totally generic container), at the beginning of our procedure we have absolutely random lay-out of our objects. Such a situation may correspond to a picture drawn using our segments like the one in fig. 1.1, where the templates of container, furnishings and pertinences are arranged in an arbitrary and "impossible" lay-out. The notion of conflict, defined as partial or complete overlapping of templates, can provide a representation and a measure of such impossibility (see fig. 1.2). As we have seen, conflicts can be ranked on a continuous or discontinuous scale by means of "fuzzy logic". "Contact" is the limit case of conflict; three contact conditions are given:

- desirability,
- admissibility
- non-admissibility.

These also can be described in "fuzzy" terms.

The following strategies may be used to solve conflicts and contacts within the constraints posed (see fig. 1.3):

i) relative movements between templates (rotations and translations);
ii) swelling and shrinking (where allowed);
iii) modification of the shape of envelope perimeters (where allowed).

Since the features of the containing space were assumed as defaults, it is clear that there are some transformations that are allowed on it and which are not allowed on specially normed fittings and elementary spaces. Our reasoner finds itself in the following situation:

- it has a start-up situation;
- it has a wide range of moves;
- it has a goal to reach:

Needless to say that its aim is to place elementary spaces within an adequate global space respecting all constraints.

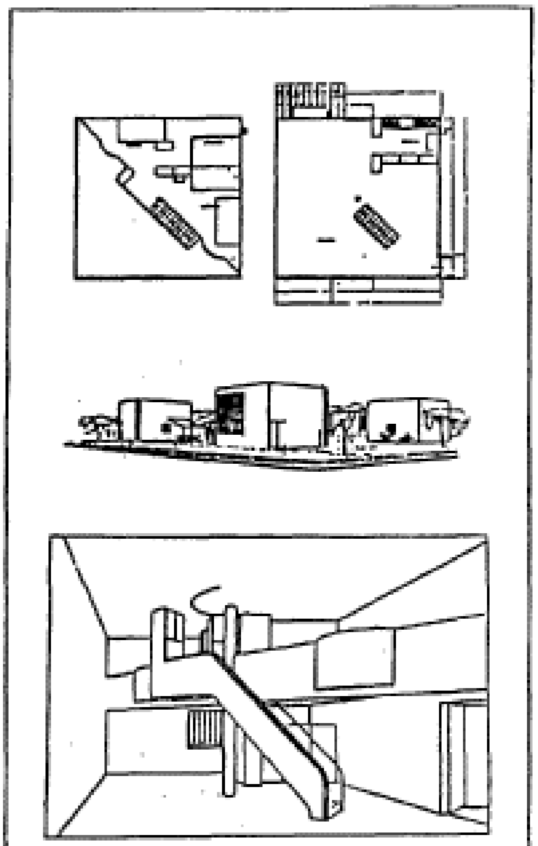
The sequence in figure 1.4 shows a qualitative representation of the path the reasoner may follow in order to find a solution corresponding to the initial condition represented in figure 1.1; figure 1.5 shows a solution where there are only desirable or admissible contacts and conflicts have been overcome. As can be seen, it helps that the reasoner does not reach only one solution. In [8] some information is given on the logical approaches employed by third reasoner; for the moment, a qualitative comment of a couple of its features is given.

This reasoner (called reasoner "A") has an analogical vision of space. The notion of conflict is managed by means of fuzzy logic and corresponds in an intuitive and straightforward way to the everyday

notion of conflict and contradiction in real spaces due to overlapping of either functional pertinences or actual objects.
The reasoner develops hypothetical reasoning. "Hypothetical" describes the sense attributed to "default reasoners" as used in the evolution strategy. In short, the reasoner tests and evaluates its inventories in relation to the start-up situation and the goals to reach, and modifies them accordingly. These inventions happen to precisely match those belonging to our cultural heritage; those which we have always been used to employing.

2. Building design

The actual design of buildings is the task of another specific reasoner called reasoner B. Also reasoner B uses an approach that employs the notion of default. In this case, however, the reasoner has inventories of buildings like those in figure 1.6a. Once a specific distributive schema is assumed as the starting point, reasoner B verifies if its characteristics comply with the pre-defined assumptions, i.e., the outcome of reasoner A's processing.
Therefore, it may well be that the spatial units included in the default schema are completely or partially inadequate because they do not match with those given by reasoner A. This causes another conflict. Figure 1.6b shows a situation in which the specifications of a distributive schema undergo modifications. More particularly, it is supposed to "swap" sleeping and living areas while keeping the North side unaltered. Conflicts are therefore generated. Conflicts in building plans have the peculiarity that a change introduced in any part of the distributive schema causes a perturbation that spreads over the whole schema. This corresponds to real situations like the following: extending a room may force us to shrink another room; if the shrinking of the latter were impossible due to mandatory constraints, it would imply the shrinking of a third room and so on. It is easy to manage the logic of this perturbation mechanism by means of a "model" of the building object, as the one discussed in [3]. Within the logic of this model it is thus possible to obtain the picture of all possible changes of the starting schema.
Like reasoner A, reasoner B is characterized by an approach defined as "hypothetical" but, unlike reasoner A, it has not an analogical vision of space. On the contrary, it works on formalized representations of building object's structures.
Reasoner B's output is a new distributive schema generated by the spreading of perturbations that comply with the set of constraints like the one showed in figure 1.6c.
We can now discuss the relationships between the two reasoners. It has already been said that the function of reasoner A is to give inputs to reasoner B. These inputs are to be perceived by B at an upper level, they are mechanisms that trigger perturbative tension in the structural distributive schemata, B takes as defaults. B's output, in its turn, is to be furtherly verified by A, etc.
We believe that the pattern of interaction between the two reasoners quite realistically reproduces a typical and widespread process of human design. It goes without saying that this is evidence of the quality of our approach, since the main problem in Artificial Intelligence is precisely reproducing current and apparently commonplace forms of reasoning.



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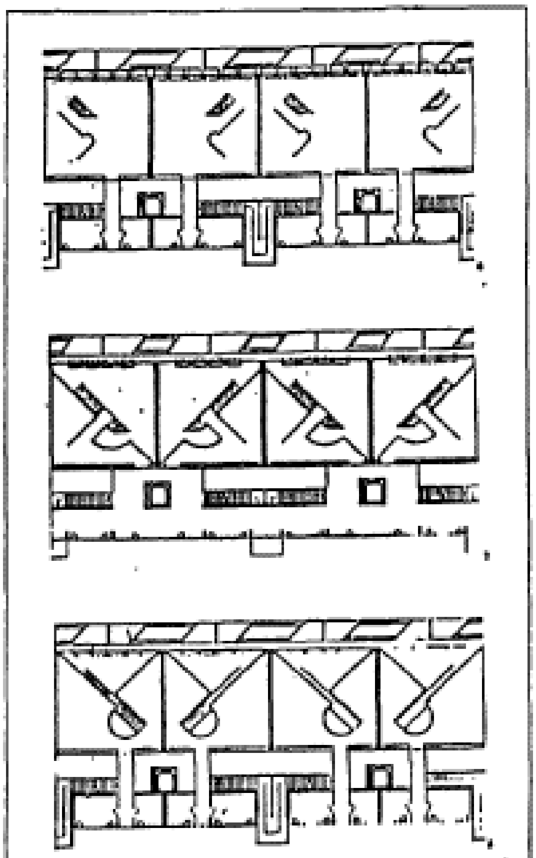

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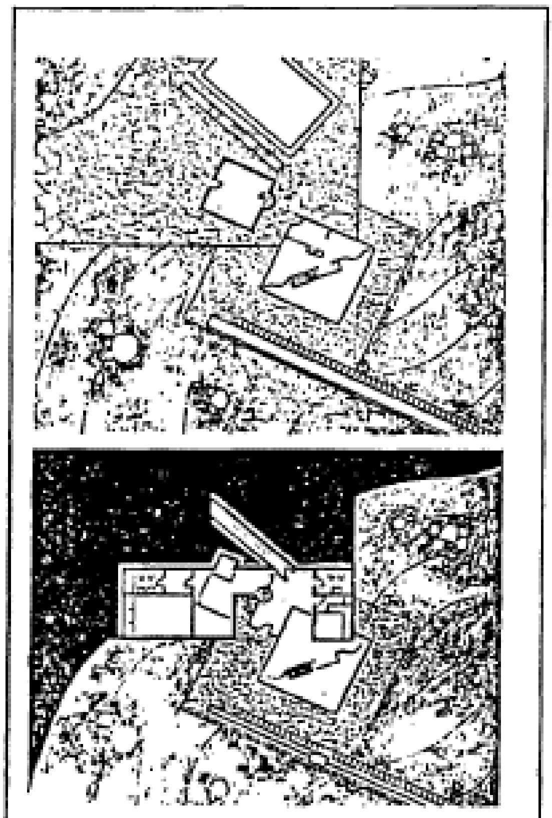

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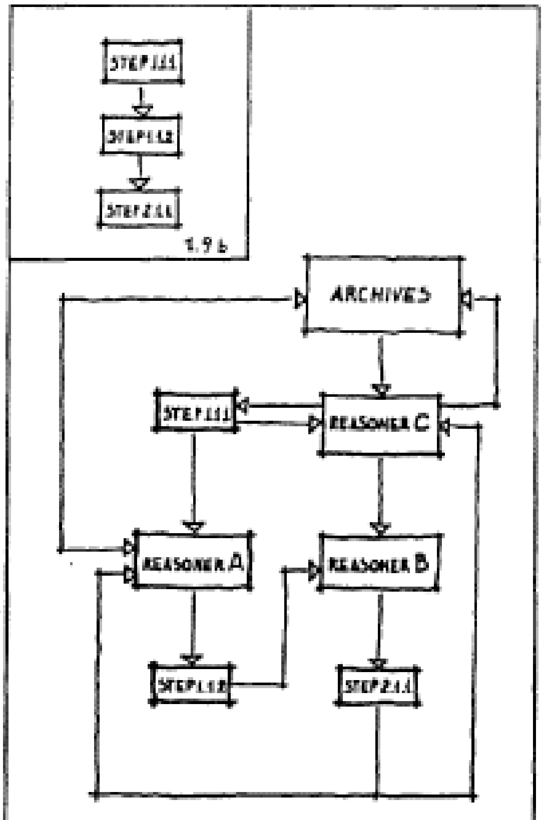

1.9b

1.9a

On the contrary, from a "theoretical" point of view, our approach may be of help to gather elements to show two counter-points:

- against those who maintain that it is possible to establish a linear deductive relationship between the two levels of meta-project. We showed that there is a hiatus between the two, that is to conflicts and contradictions;
- against those who try to overcome such gap by means of "synthetical" solutions that would not allow further analysis. We showed that there is sound grounding for complex interaction/iteration which is reproduceable and therefore open to logical and experimental explorations (reasoners as laboratories).

3. Managing meta-design stages

3. 1 Strategies for reasoner C

The schema so far developed lacks any reference to images, i.e. to the more explicitly formal structures of building objects. In other words it is assumed that image creation falls well beyond the limits of our expert system. This does not imply that a strategy of use of our reasoners cannot clarify some aspects of image-creation processes. One need only to be reminded of the role played by "memory" in such processes. Let us reflect, on our "repertories". Are they not collections of materials critically, hence culturally, selected? Such reflections lead us to think that default assumptions of distributive schemata can be furtherly analysed at a higher level. Our basic notion is that assuming a default structure is *per se* an implicit option on the ground of object images. It has already been seen that reasoner B takes in this structure and perturbs it. In a similar case, an architect may claim he or she is abstracting from its context a cultural datum coming from his or her "memory".

Let us adopt another viewpoint by going back to that meta-project stage initially untouched by analysis. Another reasoner, called C, can be conceived, that uses building programme start-up data to analyse inventories, perhaps with the help of other strategies. Such inventory may therefore be thought of as an actual cultural background for our system.

It is not expedient to define the above "other strategies" now. Yet, it is certainly interesting, to look at the open field of simulation of design behavior even with cultural intents. Let our expert system's inventory be made up of only objects by Le Corbusier, like those in figure 1.7. Starting from the "craftsman house", one can think of attaining different solutions from those reached by De Feo (figure 1.8b) or by group S (figure 1.8a) also taking the "craftsman house" as their design starting point. Our discussion led us to conceive memory more like that of "Remembrance of Things Past" than like a hard disc. However this is so only because the problems of memory within our system of reasoners have already been solved by our studies on the formalization of the building object previously referred to. Our memory is merely an archive of building objects to be stored on storage devices.

This kind of representation is well suited to storing information about large quantities of building objects on computers. Reasoner C's "memory", then, is technically viable. Reasoner C has the task of looking for the following structures in its files:

i) those that come closest to the set of goals defined at the meta-design stage.

ii) those that come closest to more generally cultural specifications. It does not seem difficult to find procedures capable, of handling the content, of point i); as for point ii) we have already stated that the problem does not lay in finding such-and-such procedure but in conceptualizing, imagining of this kind. Let us drop the issues for the moment and let us go back to overall on interaction mechanism between our three reasoners.

We started from a pattern of logical and temporal success as shown in figure 1.9a. Our stages have the following meaning (see also [13]):

1.1.1 Environmental metadesign of the systems´s spatial elements;

1.1.2 Spatial functional design of the systems´s spatial elements;

2.1.1 Spatial functional design of the building.

After our considerations on our reasoners, we reached a different pattern as is shown in figure 1.9b. It summarizes reasoners' data processing, their outputs in the proper formats and the two main feedback cycles between B and A and between B and C.

It appears to us that the main among is the introduction of formal structures (images) already at the metadesign stage (or beside metadesign, if you prefer). The following thesis can therefore be stated:

"It does not seem possible to build a theory for computer aided design that leaves images (and memory) out of consideration".

Our thesis is clear and articulate enough as to be countered and refuted (the ground for debate is obviously that of an expert system that is capable of design and which does not use images).

We have already made reference to the expert system as the place for logical experiments. If our expert system were to pass the test of Turing in the future, we would be allowed to cut the limitations from our thesis that make it applicable only to computer aided design. Such testing is not so far-fetched as it may seem. In the meantime, however, our approach can heuristically help give definite shape to the discussion about design.

3. The present state of reasoner C

It is clear now that reasoner C is the field for further research. At present, we are seeing it as a network of reasoners accomplishing the following tasks:

i) recognizing building objects' structures from graphical works according to the formal models already used to implement inventories and in such a way are to build an easy interface with the draftsman at actual design level;

ii) inferring possible plans from elevations and perspectives;

iii) assessing the building quality of a solution making sure that start-up requirements are met.

iv) using qualitative modes of reasoning as those suggested by "naive physics" in order to express judgements as "it complies with..."; it is better than..." and "... the structure is to be maintained."

v) considering alternative solutions even by questioning preferred structures previously assumed.

Some of the above points are currently under development, albeit at a preliminary stage. In particular, point i) has been studied by Puliti and Tascini (see [14]), point iii) by Puliti, Tascini and Naticchia (see [10]), point v) by Fornarelli and Lemma (see [9]). We will be discussing these developments in the future for the sake, of brevity. Prototypes for these modules and for referred to earlier are for testing at the Istituto di Edilizia and the Istituto di Informatica of the Engineering Faculty.

4. Conclusions

This paper presents an Artificial Intelligence approach to some problems of Computer Aided Architectural Design. A series of reasoners has been found for some elementary design operations and a hypothesis of interaction among has been put forward. The proposed schema poses us with questions about the handling of formal structures and about the nature of culturally-bound options on which some preliminary considerations are made.

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