THE DESIGN OF BUILDINGS AS CHANGES OF KNOWN SOLUTIONS: A MODEL FOR "REASONER B" IN THE CASTORP SYSTEM

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Abstract

The paper presents a study aimed at the modelization of a design operation of perturbation of an architectural framework in order to comply with a series of given design specifications. A formalized representation of the building object is assumed, Artificial Intelligence techniques are adopted to work on it.
It is assumed that the computer contains a database of structures representing building plans (let the dwelling be our case study).
It is also assumed that the computer carries out deformations starting from one of these structures in order to attain to a solution consistent with project specifications.
A description of the structures employed for the representation of the building body (matroids) is firstly proposed. A planning theme is then assumed, as an example, whose main feature is to maintain the outer perimeter of a dwelling, to change its internal distribution in such a way as to resemble as closely as possible to the original and yet meaningfully alter its typology.

0. Introduction

In [2] has been presented a first hypothesis for the implementation of an electronic simulator of (an expert system for) building design. In this context, the development of some "reasoners" was put forward that could carry on, in an intelligent way, some operations which were seen as typical of building design.
Prototypes of two reasoners have been developed and implemented at the University of Ancona - Istituto di Edilizia and Istituto di Informatica [6] of the Facoltà di Ingegneria. As for the second reasoner, known as reasoner B, its model was first proposed, its inferential mechanisms were then developed and its implementation was carried out. A second version of the reasoner was finally developed and is presented in this study.
It is assumed that the computer has a database of structures representing plans of building bodies (let the dwelling be our case study). It is also assumed that the computer could reshape them in order to attain to a solution consistent with the specifications of the project.
The following chapter will be devoted to the description of the structure (matroids) used for the representation of the building body.
For a thorough discussion of this structure see [4] from which useful elements for the understanding of the discussion included in the following chapter are taken. In chapter two a design theme is taken, as an example, whose main feature is to try and maintain the external perimeter of a dwelling while modifying its internal distribution in order to significantly alter its typology while keeping as close as possible to the original design.

As can be seen it is the matrix corresponding to figure 1.c; it has 9 rows and 12 columns (rows and columns, indicated in italics, correspond to the edges according to the numbering of the drawing). In fact the rank of the matroid is 9 and its rows correspond to the number on entities (partitions) which make up its base. The number of possible bases in our case equals the number of combinations of 9 elements on 12.
Therefore, this is one of the many possible matrices. Yet, it should be noted the block structure that can be associated to the matrix:

$$[I_r, D]$$

It is a characteristic structure in which I_r represents the unit-matrix whose dimensions equal the rank and which corresponds to the basic entities. The columns of D, on the contrary, identify non-basic entities and make explicit the dependence between non-basic entities and those of the base.
On further analysis of the block structure of matrix I_r, it can be seen that it is made up of two null matrices and two identity matrices; we have called the latter A and B.

$$\begin{vmatrix} A & 0 \\ 0 & B \end{vmatrix}$$

In our case, A is a 3 by 3 matrix with a definite meaning. In fact, it is determined by those base elements which make possible "adjacency" relationships between rooms, as was said in the previous chapter. Taking good precautions to always keep the representations of the partitions of adjacency within matrix A, it is straightforward to see that matrix D cannot be modified by whatsoever substitution in the remaining elements of the base. It is easy to try an intuitive test of this by substituting any element in the columns of D with any other in the rows of I_r (obviously excluding the rows of A).
Matrix D thus construed is therefore the invariant representation we were looking for: in fact, it is independent from the specific base adopted and does not make any semantic reference to the nature of rooms a, b and c.
Let us go back to the structure of representation (1) and particularly to matrix D. It can be immediately noted that a relationship can be established between the columns of matrix D and those particular cycles of the matroid which we chose to identify as corresponding to rooms. It has been seen that representation (1) is invariant to any cyclic matroid associated to any graph which is isomorphic with the given graph and that this does not depend on the base chosen nor, obviously, on metrical considerations.
More can be said on the information given by matrix D. A (local) "succession" relation can be introduced between elements belonging to the same cycle. We have already established the "adjacency" relation among cycles. Let the symbols "//" and "<<" indicate adjacency relations and succession relations respectively. We will also use capital italics to indicate cycles and the subscript for the n-th element of the cycle. It is true that $A_k << A_i$ if and only if:

$$A \mathbin{//} B \mathbin{//} \ldots C \text{ with } A_i = B_p \text{ and } C_e = A_k$$

It should be distinguished a chain of adjacencies to the right ($//^r$) and a chain of adjacencies to the left ($//^1$) (together with a succession relation and a precedence relation) between which it will be true that:

$$A \mathbin{//^r} B \text{ and } B \mathbin{//^1} A$$

The relationship between succession and precedence relations are intuitively derived. These relationships will be very useful in drawing efficient algorithms for the representation of our matroids on a coordinate system. A representable matroid is also a vectorial matroid provided there are no parallelisms and loops. Let us now represent our matroid on a R^2 Euclidean vectorial space (normed with Euclidean norm). The problem is finding a subset T of R^2 that could support a matroid M', isomorph to M, <generated by the linear independence holding in R^2>.

It is easily seen in standard representation (1) that, in our case, the three columns of matrix D hold the three relations of linear combination that, as has been seen, univocally determine our graphical matroid. vectors The columns of matrix D are, in fact, vectors that can be expressed as linear combinations of the vectors which correspond to the base according to the relation indicated in the matrix.

Let T_j be an unspecified vector t belonging to T (in our case: j = 1, 2, ..., 12; while the other index runs along rooms: i = 1, 2, 3.); in our space R^2 linear dependence relations can be expressed as follows:

$$
\begin{aligned}
&a11\ t1 \ldots\ldots\ldots a1\ 12\ t12 = 0\\
&a21\ t1 \ldots\ldots\ldots a2\ 12\ t12 = 0\\
&a31\ t1 \ldots\ldots\ldots a3\ 12\ t12 = 0
\end{aligned}
\qquad (2)
$$

where a column of matrix D corresponds to each line. Coefficients a_{ij}, thus, can only have values 0 or 1 according to the value taken by matrix D in its generic i-j-th position (taking care that the value of the coefficient indicated by the column of D is always 1).

Since the generic vector t is defined on a R^2 space, it could be expressed by using an appropriate combination of the two bases x and y:

$$t = \alpha x + \beta y$$

Expression (2) can therefore be divided into the following two groups of relations:

$$
\begin{aligned}
&\alpha 11 + \ldots\ldots\ldots + \alpha 1\ 12 = 0\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
&\alpha 31 + \ldots\ldots\ldots + \alpha 3\ 12 = 0
\end{aligned}
\qquad (2a)
$$

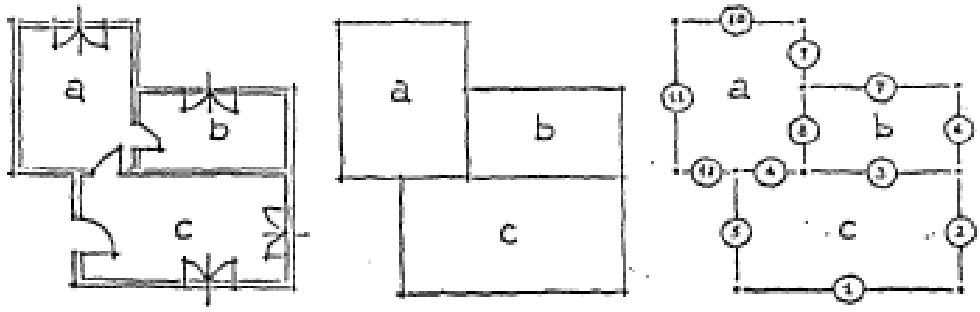
$$
\begin{aligned}
&\beta 11 + \ldots\ldots\ldots + \beta 1\ 12 = 0\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
&\beta 31 + \ldots\ldots\ldots + \beta 3\ 12 = 0
\end{aligned}
\qquad (2b)
$$

which express the (obvious) condition that the sum of the projections of the sides of a polygon on the axes of a coordinate system is null (Congruence Relations). In the following chapter the notion of matroid will be employed not only to efficaciously manage the formalized representation of building objects, but also to tackle some preliminary problems of design.

2. Generation of hypotheses on space organization

In the rest of the present chapter a cognitive structure is discussed that enables us to repeatedly fragment a problem in many sub-problems. Such structure, however, should not be conceived as a model of deterministic reasoning. The problem we are to tackle is that of the organization of a space pre-defined by topological, metrical and functional specifications.

Our example will be the division of a dwelling in rooms; other examples, however, might be the division of a floor in dwellings, the division of land in lots, etc. These differ from one another in term of their characteristic scale factor, but they could be dealt with the same conceptual frame. Let us suppose that we have a pre-defined space (figure 2.1), i.e. the dwelling's perimeter, and that we have to divide it in three rooms, each one adjacent to the other two. For the sake of simplicity, let us ignore for the moment other non-topological specifications.



1a) Building object with three rooms 1b) Wire-frame scheme 1c) Planar graph corresponding to the scheme

Fig. 1

	5	7	11
1	1	0	1
2	1	1	0
3	0	1	1
4	1	0	0
6	0	1	0
8	0	0	1
9	0	0	1
10	0	0	1

fig. 2.2a

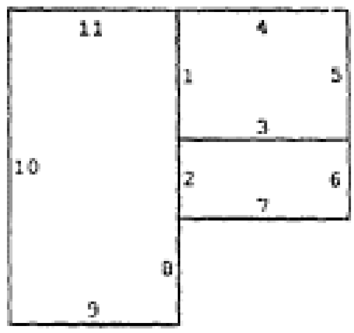


fig. 2.2b

	6	8	12
1	1	0	1
2	1	1	0
3	0	1	1
4	1	0	0
5	1	0	0
7	0	1	0
9	0	0	1
10	0	0	1
11	0	0	1

fig. 2.3a

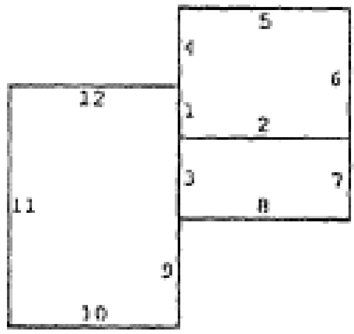


fig.2.3b

	7	9	14
1	1	0	1
2	1	0	1
3	0	1	1
4	1	1	0
5	1	0	0
6	1	0	0
8	0	1	0
10	0	0	1
11	0	0	1
12	0	0	1
13	0	0	1

fig.2.4a

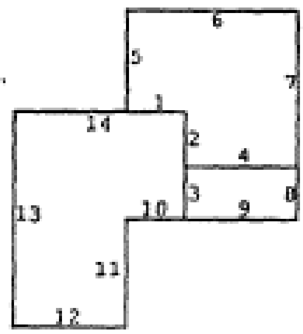
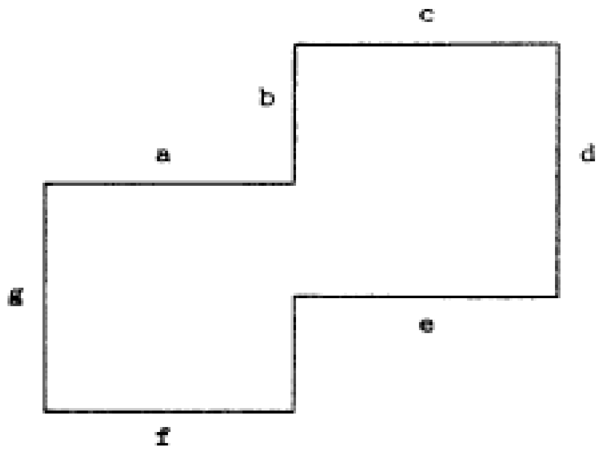


fig.2.4b

Figure 2. 1



the specification concerning room entails the choice of a family of matroids with three cycles in the prescribed relations of adjacency; some of these comply with parameter constraints, some do not. For instance, the three matroids in figures 2.2a, 2.3a and 2.4a, represented using only last chapter's matrix D, correspond to the topologies shown in figures 2.2b, 2.3b and 2.4b respectively.
The topology in figure 2.2a is not compatible with the required perimeter while the others are compatible and differ only for the number and position of their partitions.
In order to find a family of matroids characterized by three adjacent cycles, one should only carry on a simple analysis of the matrix that describes it; selecting a sub-family of matroids compatible with the assigned perimeter, instead, is a far harder task. This is so because computers do not have icon-like knowledge, unless via symbolic terms. It could be noted, however, that it is possible to find a correspondence between the perimetrical elements shown in figure 2.1 and those shown, for instance, in figure 2.3b by matching sides and corners and/or disassembling sides into sequences (side corresponds, to sequence "6" and "7").
This allows us to make use of syntactic techniques typical of the theory of languages for the automation of perimeter correspondence analysis. Any perimeter can be described as a sequence of sides, left corners and right corners in accordance with a pre-established clockwise or anti-clockwise way of reading them. As an example, the perimeter of figure 2.1 may be described as follows:

┐ s ┘ s ┐ s ┐ s ┐ s ┘ s ┐ s ┐ s (1)
(the sequence: ┐ a ┘ b ┐ c ┐ d ┐ e ┘ f ┐ g ┐ h corresponds to it)

where: "s" stands for "side"
┐ stands for "clockwise corner"
┘ stands for "anti-clockwise corner".
The sentence (1) can be generated by the following grammar G:
R1. <perimeter> ::= <perimeter> ┘s | <perimeter> ┐s | ø
R2. s ::= s' -- s | s
where the second rule defines the disassembling of a side into two successive and aligned sides (-- is the symbol for "flat corner")
Figure 2.5 shows the syntactic tree which generates the perimeter of figure 2.1 through grammar G. The same syntactic tree, can generate the following sentence by applying rule R2 (figure 2.5):

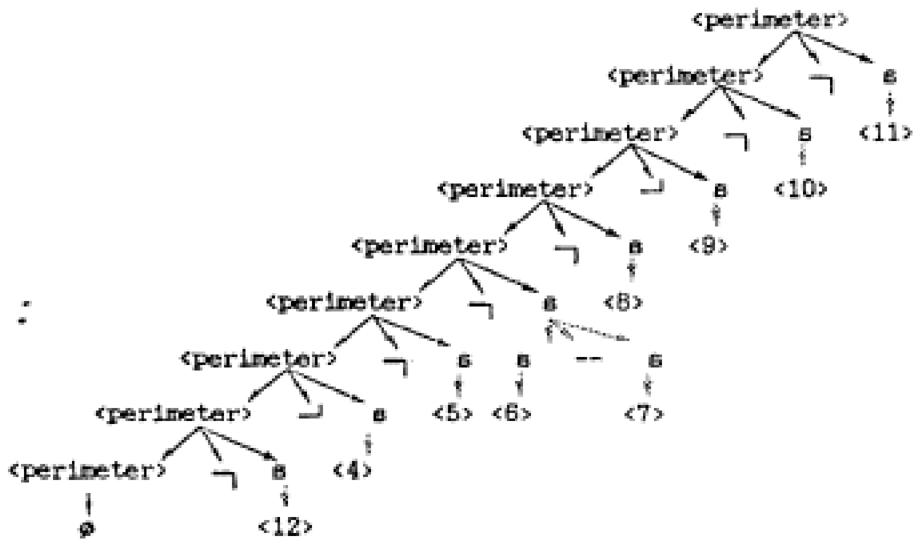
┐ <12> ┘ <4> ┐ <5> ┐ <6> -- <7> ┐ <8> ┘ <9> ┐ <10> ┐ <11>

which describes the perimeter of figure 2.3b, there is no way for it to generate the following sentence:

┐ <11>-- <4>┐ <5>-- <6>┐ <7>┘ <8>┐ <9>┐ <10>

which describes the perimeter of figure 2.2b. Thus, the matroid in figure 2.2a can be eliminated employing parsing techniques typical of the theory of languages.

Figure 2.5



The next selection of compatible matroids can be carried out by minimality criteria, therefore the matroid in figure 2.3a is, at first glance, to be preferred to that in figure 2.4a. Let us now introduce some functional specifications; for example the three rooms can be defined as bedroom, bathroom and entrance/living-room with a cooking corner. This stage poses us with new problems that can be dealt with the following conceptual operations:

i) Attributing semantic features to each room and generating dimensional hypotheses;
ii) Analysing deformations' global consistency and management;
iii)Analysing local functionality.

In the first operation a function must be attributed to each previously identified room, taking into consideration any constraint based on preferences, contiguity with external elements, accessibility, etc. At this stage, dimensional hypotheses can be made provided the topological analysis left metrical aspects unspecified.
At this level of abstraction it is therefore solved the problem of generating a specific instance of dwelling with the following features: compatibility with a pre-established topology within a definite global space; compliance with a set of functional goals.
A such conceived framework can be dealt with by reasoners A and B together, previously introduced; they carry on operations 2 (reasoner B) and 3 (reasoner A). Reasoner B can be structured as a planner working on a logic which associates goals and actions and whose outcome is the passage to a new state where the goal is hopefully reached. This structure can be schematized as in figure 2.6:

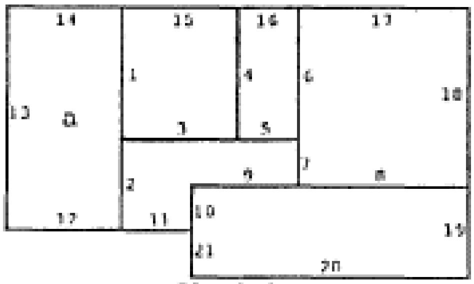


fig.2.7a

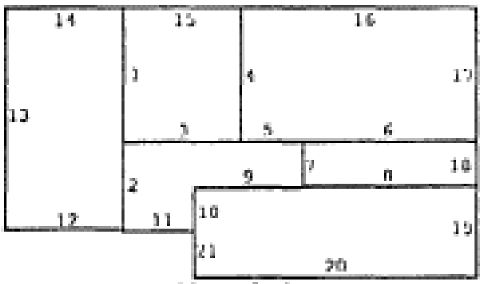


fig. 2.8a

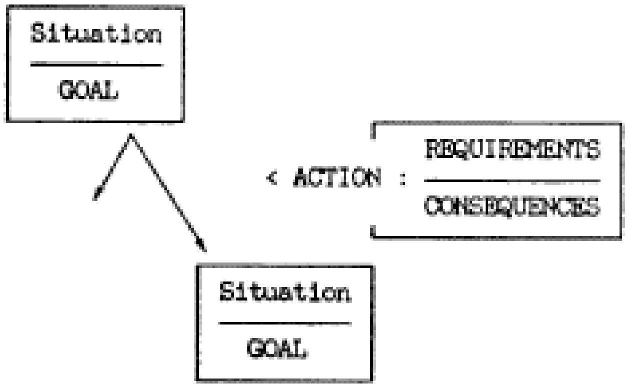
	11	14	15	16	18	21
1	0	1	1	0	0	0
2	1	1	0	0	0	0
3	1	0	1	0	0	0
4	0	0	1	1	0	0
5	1	0	0	1	0	0
6	0	0	0	1	1	0
7	1	0	0	0	1	0
8	0	0	0	0	1	1
9	1	0	0	0	0	1
10	1	0	0	0	0	1
12	0	1	0	0	0	0
11	0	1	0	0	0	0
17	0	0	0	0	1	0
19	0	0	0	0	0	1
20	0	0	0	0	0	1

fig. 2.7b

	11	14	15	16	18	21
1	0	1	1	0	0	0
2	1	1	0	0	0	0
3	1	0	1	0	0	0
4	0	0	1	1	0	0
5	1	0	0	1	0	0
6	0	0	0	1	1	0
7	1	0	0	0	1	0
8	0	0	0	0	1	1
9	1	0	0	0	0	1
10	1	0	0	0	0	1
12	0	1	0	0	0	0
13	0	1	0	0	0	0
17	0	0	0	1	0	0
19	0	0	0	0	0	1
20	0	0	0	0	0	1

fig. 2.8b

Figure 2.6



Any goal can be reached by means of one or more actions related to it in the knowledge base of the system. At the start, actions can be chosen according to requirements that must be met in the current situation for the action to occur. Any action has its consequences, i.e., the changing of one or more facts, which, in their turn, generate a new situation. This is put under assessment since the changes introduced may produce further problems that raise new goals. The planning process must prevent cyclic paths; it succeeds when it leads to a situation which does not pose any further goals, it fails when no acceptable action is found. In case of failure, the matroid originally chosen is likely to be inadequate; a complete structural change is then necessary, this often involves adopting a different matroid. The passage from the structure in figure 2.7a, corresponding to the matroid in figure 2.7b, to structure 2.8a, corresponding to the matroid in figure 2.8b, is an example of this.

3. Conclusions

The present paper contains a study on the necessary steps to take in order to attain structures consistent to given goals assuming as starting point a formalized representation of the building object. The design operation here analysed is considered as typical of much design processes. The reasoner that is capable of carrying it on can be included in a series of different reasoners that can go through different design approaches.

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1. A representation of topological and geometrical structures of the building object.

The aim of this stage of the present study is to find a structure for the representation of the building object (B.O.) in a vector space. The structure should also be invariant from any semantics (usage modes, functionality, etc.) that could be superposed to the physical structures of the B.O. and "minimal" with respect to information efficiency parameters.
Let us take an horizontal projection of a B.O. - which, in our example, is made up of three rooms as the one drawing in fig. 1a. A first level of abstraction enables us to describe the three space units system in terms of partitions, i.e. entities which divide, separate in space. The system of partitions can be schematized as in fig. 1b, making abstraction from any features different from the ones there represented (this abstraction will be given back concreteness later on).
In fig. lc the nature of planar graph of the previous sketch is made explicit. Joints and edges are pointed out, edges are numbered from 1 to 12.
It is also easy to single out, among all possible cycles, the ones corresponding to the three rooms (a, b, c).
Let us turn to the notion of matroid. Matroids are algebraic structures allowing mathematical representations of both hypergraphs and graphs. Matroid theory [9] was first introduced in order to characterize, in a strict and general way, the notion of linear dependence and independence in vector spaces. It was then developed and adapted to the problems linked to graph theory. We employ it in the present study, albeit we make only general reference to it, because it provides a powerful language capable of expressing all the contents of those studies that used a user graph theory for the problems of layout. Matroid theory has other qualities as well, i.e. it affords a representation which is simple and independent from the various semantic contexts. In fact our problem was to represent building objects in a vector space making reference only to their typological and metrical features. Let us then give one definition [1].
Let S be a finite set and P(S)=P a family of subsets of S; the elements of P are called "cycles". The pair {S,P) is a matroid if it verifies the following axioms:
- The void set is not included in P.
- Any two elements of P given, if one is included in the other then the two elements coincide.
- For any element s of S that could be defined as an intersection of two cycles then exicts a further cycle P° included in the union of the two cycles to which element S has been subtracted.
A subset of S, S', where no cycles are included is called "independent set". Let "rank" of a matroid be the highest number of elements of S included in an independent set and let "base" be the maximum independent subset.
Matroids can be associated to graphs like those in figure 1.c, they can also be represented in "standard" form as follows:

	8	4	3	1	2	6	10	11	12	5	7	9
1	1	0	0	0	0	0	0	0	0	0	1	1
2	0	1	0	0	0	0	0	0	0	1	0	1
3	0	0	1	0	0	0	0	0	0	1	1	0
4	0	0	0	1	0	0	0	0	0	1	0	0
5	0	0	0	0	1	0	0	0	0	1	0	0
7	0	0	0	0	0	1	0	0	0	0	1	0
9	0	0	0	0	0	0	1	0	0	0	0	1
10	0	0	0	0	0	0	0	1	0	0	0	1
11	0	0	0	0	0	0	0	0	1	0	0	1

(1)