RATIONAL DATA MODEL: AN APPROACH FOR BUILDING DESIGN AND PLANNING

Mario De Grassi

Department of Building and Environmental Control Technologies

Rome University "La Sapienza", Roma, Italy Via Eudossiana N°18 - 00184

Summary

A model of the building object utilizing the typical formal structures of the relational data model is presented, which allows interactive design procedures to be foreseen and at the same time the use of the model for a data base containing information on building objects, to be used for normative planning and for building design.

Introduction

This paper presents a model for the representation of building objects which allows:
a) a data base comprising the geometrical and topological characteristics of the building objects and the semantics ascribed to them by their actual use.
b) the implementation of interactive design procedures and of procedures for the calculation of performance and cost parameters.
This appears particularly important in those cases where a pre-design statistical analysis of the dwellings and the families who live there is carried out to identify the preference system and goals to be taken as input for the design phase. This approach makes it possible to identify the variables for description of building object/mode of use nexus which retain the same meaning (semantic stability) even in very different cases. The same system of variables can be effectively utilized in the interactive design phase. The relational data model appears to be the, instrument best suited for the achievement of the goals indicated. The problems concerning the representation of the building object through the relational data model are discussed in paragraph 1. In paragraph 2 we examine different approaches that, by means of statistical analyses of the data contained in the relational data base, allow identification of variables which, optimizing the objective functions indicated by the users, assume a normative character and statistical significance of local validity.

1. - Building objects and the relational data model

The problem we are dealing with is how to represent a building object as it appears as abstracted from the design documents (lay-outs, sections, etc.) through formal structures that can be implemented in a relational data base.
The tern "building object" is used to mean a structured set of space units. "Space units" mean a finite space delimited by partitions (horizontal and vertical) each having two sides, the first facing the space unit in question, the second facing another space unit adjacent to the first one.
It is evident that the partitions determine the structure of the building object, since they determine the adjacency relations between the space units themselves.
At a first level of abstraction corresponding for example to a 1:200 scale plan, in addition to the adjacency relations and to the length of the corresponding partitions, the geometrical characteristics and the shape of the space units will be of interest.
Assuming that the space units can be represented by polygons, the "characteristic geometry parameter" is taken to be the size of the angle between the polygon's sides, and the "characteristic shape parameter" is the number of concave internal angles of the polygon itself (fig. 1).
At the most elementary level of representation, the information on the building object is thus comprised by knowledge of its A.G.F. (Adjacency, Geometry, Form-Shape) structure and the lengths of the partitions corresponding to the adjacency relations.
Our discussion will be developed at this level. Later it will be seen how any other information that can define the B.O. in more detail can be easily included in the proposed model (Fig. 2).
For practical reasons let us assume that the S.U.'s geometry is com posed of orthogonal polygons. This enables us to identify for each S.U. four possible bearings (North, South, East, West) for the relative partitions.
From now on it will be assumed that the main features relative to relational data models are known, namely the n-upla, the relation, the relational data base, the data base scheme etc.
it is assumed that the notation t.H will indicate the value assumed by H in the t n-upla.
in the relational data model a B.O. can be represented through the following types of relations:

(1) $\mathbf{R_1}$ **(<u>A</u>,<u>B</u>,<u>C</u>,X_1 , ... ,X_n**

A B.O.'s serial number
B S.U.'s serial number

C bearing : North = 4k + 1 where k 0,1,2 ....n
West = 4k + 2
South = 4k + 3
East = 4k + 4

X_1 length of the adjacency to the B = 1 S.U.
.
.
.
X_n length of the adjacency to the B = n S.U.

ABC : primary key

(2) R_{2i} (ABCX$_i$ α_1 y_1 , ... , α_m,y_m) where

X_i = length of the adjacency of the B S.U. to the i-th S.U.

Y_1 = length of the first component of X_i
.
.
.
y_m = length of the m-th component of X

Y_i precedes Yi+$_1$ anti-clockwise

m = maximum acceptable value for the shape's complexity
α_i = Boolean variable which takes the value of α = 1 in the following case:

a) in case of North of West bearing if Y_i precedes in the traverse a Y component with South or East bearing respectively

b) in case of South or East bearing if Y_i follows a Y component with North or West bearing.

In any other case it takes the value of α = 0.

ABCX$_i$ primary key

Relation (1) for each building unit B of an building object A gathers according to bearing C all the information relative to the length of the adjacence to S.U. B.
Relation (2) takes into account, in case of form complexities not manageable with (1), the necessity to represent the length of the X_i adjacence through its Y components.
The bearing taken (anti-clockwise) for the polygon sides and the, α

variables permits univocal identification of X_i.
The following constraints therefore apply:

$$(3) \qquad \forall\, t \in R_1 [t \cdot B = j \wedge t \cdot X_j = 0]$$

For each S.U., the self adjacence is not given.

$$(4) \qquad \forall t \in R_1 [t \cdot A = a \wedge t \cdot B = b \wedge t \cdot C = c]\ \exists\ s \in R_1 [s \cdot A = a \wedge s \cdot B = b \wedge s \cdot C = c+2 \wedge (\sum_i t \cdot X_i = \sum_i s \cdot X_i)]$$

For each S.U., the sums of the opposite sides are equal.

$$(5) \qquad \forall t \in R_1 [t \cdot A = a \wedge t \cdot B = b \wedge t \cdot C = c]\ \exists\ t_1, t_2, t_3 \in R_1 [(t_1 \cdot A = a \wedge t_1 \cdot B = b \wedge t_1 \cdot C = c+1) \wedge (t_2 \cdot A = a \wedge t_2 \cdot B = b \wedge t_2 \cdot C = c+2) \wedge (t_3 \cdot A = a \wedge t_3 \cdot B = b \wedge t_3 \cdot C = c+3)]$$

The 4 bearings are given for each S.U.

$$(6) \qquad \forall t \in R_1 [t \cdot A = a \wedge t \cdot B = k \wedge t \cdot C = c]\ \exists\ s \in R_1 [(s \cdot A = a \wedge s \cdot B = j \wedge s \cdot C = c+2) \wedge (t \cdot X_j = s \cdot X_k)].$$

To each X_j adjacence of the K-th S.U. corresponds (with equal length) the X_k adjacence of the j-th S.U. (Fig. 3).

$$(7) \qquad \forall t_1, t_2 \in R_1 [(t_1 \cdot A = a \wedge t_1 \cdot B = b \wedge t_1 \cdot C = c \wedge t_1 \cdot x_j \neq 0) \wedge (t_2 \cdot A = a \wedge t_2 \cdot B = b \wedge t_2 \cdot C = c+1 \wedge t_2 \cdot X_j \neq 0)]\ \exists\ s_1, s_2 \in R_{2j} [(s_1 \cdot A = a \wedge s_1 \cdot B = b \wedge s_1 \cdot C = c) \wedge (s_2 \cdot A = a \wedge s_2 \cdot B = b \wedge s_2 \cdot C = c+1) \wedge (s_1 X_j = t_i \cdot X_j) \wedge (s_2 \cdot X_j = t_2 \cdot X_j)]$$

In case of a S.U. adjacence with another S.U. on more than one bearing, the description of the adjacences between the two space units must employ the R_{2j} relations.

$$(8) \qquad \forall t \in R_{2j} [t \cdot A = a \wedge t \cdot B = i \wedge t \cdot C = c] \exists s \in R_{2i} [(s \cdot A = a \wedge s \cdot B = j \wedge \wedge s \cdot C = c + 2) \wedge (t \cdot Y_1 = s \cdot Y_m) \wedge \ldots\ldots \wedge (t \cdot Y_m = sY_1)]$$

Analogous constraints to (6) for the R_{2j} relations

$$(9) \qquad \forall t \in R_{2j} [t \cdot X_j = \sum_i t \cdot Y_i]$$

The length of the X_j adjacence equals the sum of its components.
Together the n-elements sets having the same t.A. value comprise all information necessary to reproduce the lay-out of the S.U. at the selected level of approximation. A drawing algorithm will in fact proceed to draw a S.U., moving anti-clockwise and orientating the segments corresponding to the adjacences belonging to the same bearing, with the following criteria: it is said that $X_j > X_i$ (X_j preceeds X_k anti-clockwise) if:

$$(10) \qquad \forall t (C = c, X_j, X_k) \exists s, q [(s \cdot C = c + 3 \wedge q \cdot C = c + 2) \wedge (q \cdot B = s \cdot B \neq t \cdot B) \wedge \wedge (q \cdot X_r = t \cdot X_k)]$$

expressing the behavior at the nodes according to what is indicated in Fig. 3.
If the conditions indicated in (7) apply, the broken line will be rebuilt utilizing the Boolean variables α.
Because of lack of space, the model will not in this context be developed further to allow for representations at higher levels of approximation.
Those who are familiar with the relational data base will appreciate how easily this can be done.
The introduction, in addition to the integrity constraints indicated, of further constraints corresponding to individual requirements, is the basis for an interactive design approach. The use of relational algebra allows the space units to be aggregated and broken down allowing the scale changes and detailed analysis required in design.

2. - A statistical approach to programming and normative problems
We have seen how a relational data base structured in this manner permits the representation of building objects and how this can be a support for the implementation of interactive design procedures. At the same time any real building object can be represented in such

data base. In [16] procedures and algorithms that allow for an automatic implementation using interactive plotting tablets from lay-out and section drawings are shown.
Given a building object, the space units are characterized by the value of B. Identical building objects can be used in different manners by different users in relation to specific "way of use" as a function of different cultural models and of the family's demographic and social characteristics.
If we call P the set of possible ways of using the space units, we can assume an injective function $P:B \rightarrow P$ that indicates the specific way of use for each building object.
In this manner we can implement the building object in the data base in through its way of use.
in [9,10] we have shown a decisional model capable of identifying a set of design-variables that permit the achievement of qualitative characteristics for the building objects to be designed, that are generally in keeping with the preference systems and income levels of the users, compatibly with the pricing system and with a production cost function defined by the offering agent.
Such sets of variables are applicable as indicative (normative) values suggested for a specific local environment and for specific categories of users.
Let us assume we have carried out a survey of the dwellings in a specific urban environmental context and their relative market prices together with a survey of the social and economic parameters of the individual families living there.
Let us also assume we have surveyed for each dwelling a set of the facilities Z provided by each individual dwelling, compared with a list of requirements.
The structure of the previously described relational data base enables us to obtain, for each surveyed and implemented building object (dwellings in our case), the set (P,n) that specifies the group of adjacencies X associated with each space unit, used according to way of use p. Whatever the building object may be, in a set the same significance is maintained by each element. Since in the data base (as we have seen) a value of X. is related to each pair (P,n) we can assume that a vector X can be associated to each BO. that is capable of describing it completely.
Through statistical analysis, using the information provided by the data base, we can specify the n functional relations.

$$(11) \qquad Z_i = f(\bar{X})$$

that interpret the level of facilities offered as depending on the parameters X that describe the building object. The regression procedure can be normally used and whenever the Z_i

variable is Boolean, discriminant analysis can be used.
If we consider that the goal of the design operation is to improve, in comparison to the reference context, the facilities provided, we can further interpret (11) as a system of objective functions depending on the parameters X. which in this case will be considered as design-decision variables.
In [10] we have show an approach to such a vectorial optimization problem (V.O.P.) which entails reference to the concept of "hedonic price" of each individual Z_i.
The hedonic prices can be obtained statistically from the functional relation:

$$(12) \qquad P_n = f(\bar{Z}_i)$$

The hedonic prices can be defined as:

$$(13) \qquad P'_k = \frac{\partial P_n}{\partial Z_k}$$

If we follow the procedure for the solution of a V.O.P. suggested in [6,10], we can see that all the necessary information for the solution of the problem is contained in the matrix

$$(14) \qquad \Lambda_\varepsilon = \begin{vmatrix} \lambda_{11}(\varepsilon) & \cdots & \lambda_{1n}(\varepsilon) \\ \vdots & \ddots & \vdots \\ \lambda_{n1}(\varepsilon) & \cdots & \lambda_{nn}(\varepsilon) \end{vmatrix}$$

where Λ_{ij} is Lagrange's coefficient relative to the Z_j function of the i-th problem

$$(15) \qquad \max = Z_i(\bar{X}) \qquad i = 1,2,\ldots\ldots,n$$
$$\bar{X} \in V_\varepsilon^{(i)}$$

where $V^{(i)}$ is the system of constraints V without the inequality i-th with

$$(16) \qquad V_{\varepsilon}\begin{cases} Z_1(\bar{X}) \geq Z^*_1 - \varepsilon_1 \\ . \\ . \\ . \\ Z_n(\bar{X}) \geq Z^*_n - \varepsilon_n \end{cases}$$

introducing a tolerance defined by the distance $_i$,...... $_n$ from the individual optimums Z^*_1 ,.... , Z^*_n that is considered allowable. Knowing the hedonic prices, we can utilize the relation:

$$(17) \qquad \frac{P'_i}{P'_j} = \lambda_{ij}$$

which makes the problem's solution easy from the operational point of view and of clear conceptual meaning. Having a cost function

$$(18) \qquad C = f(\bar{X})$$

assuming

$$(19) \qquad \lambda_{ic} = \frac{\partial Z_i}{\partial C} = 1$$

we would also impose the condition that the marginal costs be equal to the prices.
It is possible to demonstrate how the same solution, applies to each problem (15).
The set of the X values obtained in this manner will appear as a subset of adjacencies. This is because the generation of the (11) through statistics requires the elimination of the variables strongly correlated to each other.
For this reason the design problem relative to the use of X as a normative indication is an open one (with no univocal solution) since the X-set is indicative of possible configurations capable of optimizing the complex system of objectives given.
The introduction of constraints (3,....,9) will help to define the problems and to suggest the concrete design options in the range of "theoretically" optimum solutions.

Conclusions

A building object model utilizing the typical formal structures of the relational data model has been presented, which allows interactive design procedures to be foreseen and at the same time the use of the model for a data base containing information on the building objects that can be used for the solution of normative and design problems.

Bibliography

[1] Atzeni P., Batini C., De Antonellis V. "La teoria relazionale dei dati", Boringhieri, 1985.

[2] Bellacicco A., Labella A., "Le strutture matematiche dei dati", Feltrinelli, 1979.

[3] Berge C. "Theorie des graphes et ses applications", Dunod, 1968.

[4] Carrara G., Paoluzzi A. "Systems approach to building program planning", Istituto di Architettura, edilizia e tecnica urbanistica, Facoltà di Ingegneria, Roma, 1980.

[5] Carrara G., Novembri G. "Constraint-Bounded Design Search", CAAD Futures, Deft, 1985.

[6] Chankang V., Haimes Y.Y. "Multi-objective Decision Making", North-Holland, 1983.

[7] Chang C.C., Keisler H.J. "Model Theory", North-Holland, 1973.

[8] Date C.J. "An Introduction to Database Systems", Addison-Wesley

[9] De Grassi M. "Qualità e costi nell'edilizia residenziale: tecniche analitiche per un approccio statistico", Università di Roma, 1982.

[10] De Grassi M. "Edilizia residenziale: scelte di politica normativa e vincoli di costo", Università di Roma, 1983.

[11] Graver M., Lewandowsky A., Wierzbicki A.P. (ed.) "Multiobjective and Stochastic Optimization", IIASA, 1982.

[12] Mendelsen E. "Introduction to Mathematical Logic" Van Nostrand Company, Princeton, 1964.

[13] Monk D. "Introduction to set theory", Mc Graw-Hill, 1969.

[14] Nilsson N.J. "Problem-solving methods in artificial _intelligence", New York Mc Graw-Hill, 1971.

[15] Nilsson N.J. "Principles of artificial intelligence", Springer-Verlag, 1982.

[16] Paris G. "Procedures and algorithms to implemented a Relational Database in support of building design", IV C. CAADE. Roma, 1986.

[17] Preparata F., Yeh T. "Introduction to discrete structures for computers science and Engineering", Addison Wesley, 1963.

[18] Lombardo Radice L. "Istitutioni di algebra astratta", Feltrinelli, 1982.

[19] Robinson A. "Introduction to Model Theory and to the Metamathematics of Algebra", North-Holland, 1963.

[20] Steadman J.P. "Architectural Morphology", Pion Limited, 1983.

[21] Welsh D.J.A. "Matroid Theory", Academic Press, 1976.

[22] Winston P.H. "Artificial Intelligence", Addison Wesley, 1984.

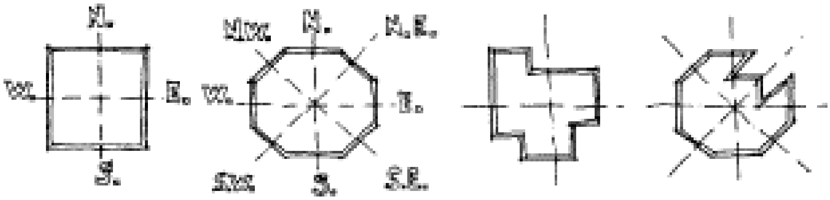

Fig. 1

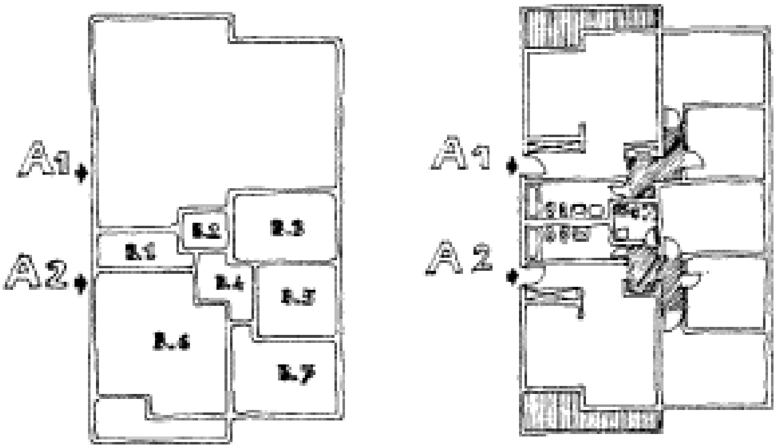

Fig. 2

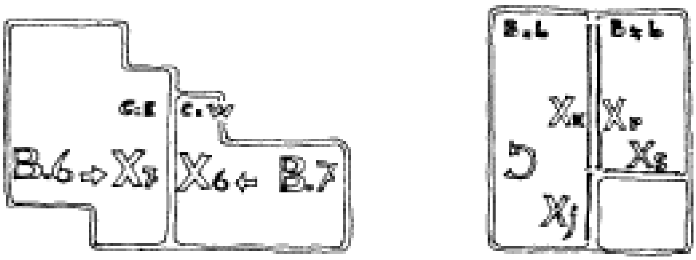

Fig. 3

Fig. 1 - A number of the geometries possible. As far as the base polygons are concerned, the R_2j relationships make it possible in any case to deal with complicated configurations.

Fig. 2 - At right: configurations of the dwellings at levels A and B.
At left: the further development of the database makes it possible to attain the desired processing level.

Fig. 3 - At right: the logic of adjacencies in the R_1 relationship.
At left: the criterion for obtaining the procedure relationship between segments X_k and X_j

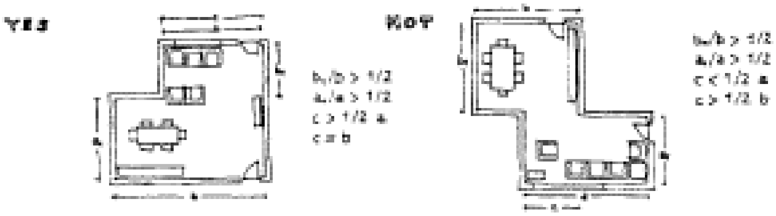

fig. 4

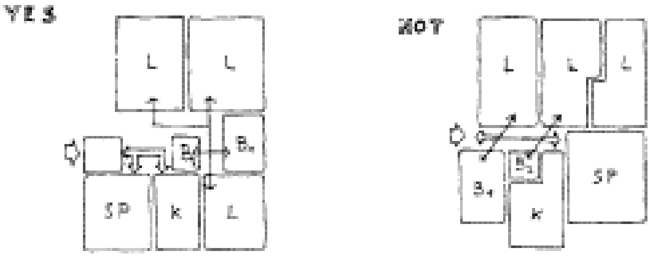

fig. 5

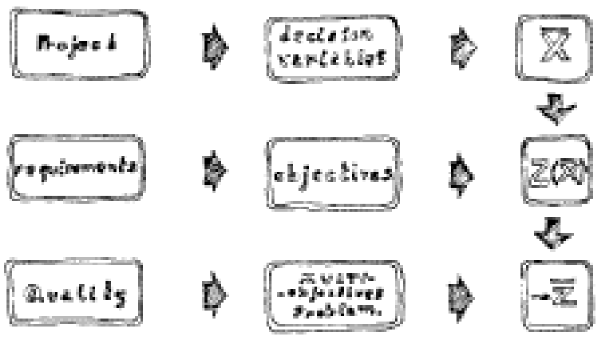

fig. 6

Fig. 4 and 5 - Usability requirements: control hypotheses with quantitative and Boolean variables.

Fig. 6 - Schema: the problem of the norm, as a multi-objective optimization problem. The X-variables are the variables contained in the database illustrated.