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UTILIZATION OF RULES FOR MODULAR COORDINATION IN RELATIONAL MODELS TO BE EMPLOYED IN CAAD

Cristina Cocchioni*, Saverio Mecca**

* Associate Professor - ITEPAC, Facoltà di Architettura, viale Pindaro, Pescara.

** Researcher, Dipartimento di Processi e Metodi della Produzione Edilizia, Facoltà di Architettura, via San Nicolo, Firenze.

Abstract

The paper deals with the structure of experimental software to be used for the interactive relational database and a graphic package. Proposed is the development that considers the main implications of a modular space grid for the project´s development already from the stage of preliminary wire-frame design.

0. Foreword

The paper presents a model aimed at representing the structure of the space of modular coordination in which design work can be carried out. A relational approach (yet a prolog-like approach) is adopted so that the model can be the natural extension of the building object model already developed in Ancona.
In that context, the building object is represented by means of a relational database according to a mode which has been defined as one of "intrinsic representation". The characteristic structure of a building object and all the information concerning design decisions are represented in a way that is wholly independent from coordinate systems. As a matter of course, a coordinate system is used at the stage of graphic representation, i.e. when editing the graphic text, according to the rules proper to the communication system and to the specific communication needs required by the situation.
The paper assumes the same approach and aims at printing out the intrinsic features of modular coordination spaces (modules, grids), the elements intervening in these spaces (plans, lines, points), the relationships between elements and, eventually, the relationships between elements and technical models and components, as they are described in the quoted relational models.
The first aim of the paper is to provide a tool which ensures the consistency between the structures of the building object and those of the space of modular coordination in order to explore one and the same database; in other words, a tool for integrating into a modular space of coordinate system any dimensional configuration of the building object and of its components.

The second goal is to lay the foundations, for a topological taxonomy (in the linguistic sense) of the building elements and of the joining of all building elements which would make up the technological environment of the database. This precedes the selection of decision strategies regarding the size and mutual placing of the building elements within the expert system.

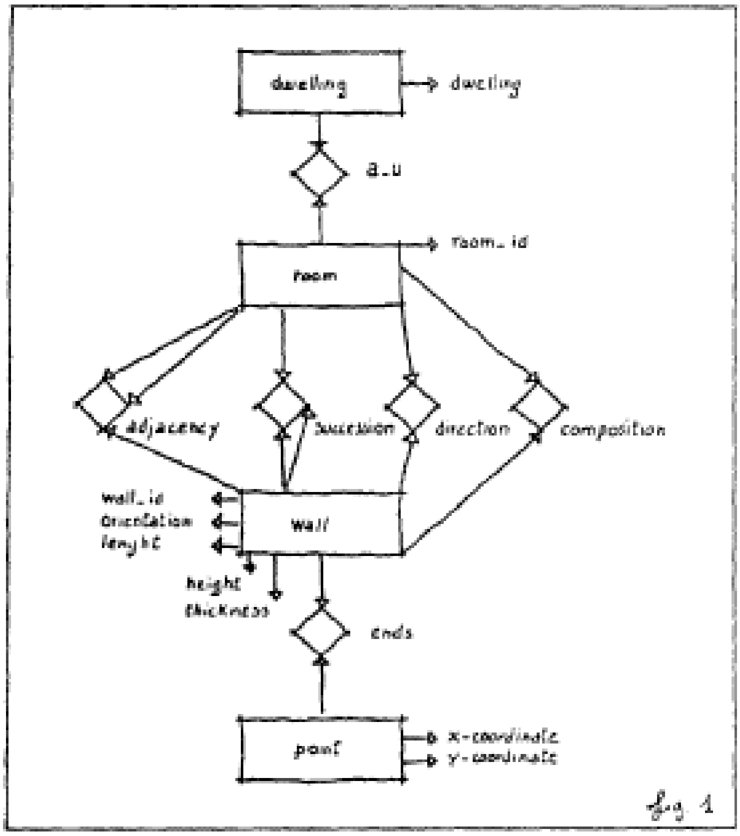
1. *A Relational model for building objects (BOs)*

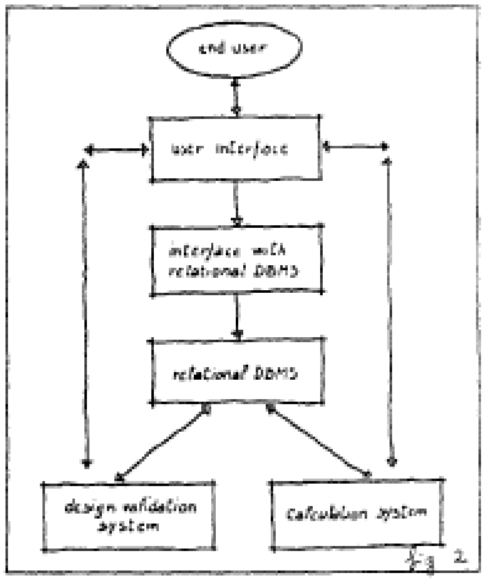
A vectorial representation of the building object using results from the matroid theory has been presented in [3]. This has been further developed into a formalized representation by means of a language of the first order and patterns to be used in relational databases have thus been deduced.
Vectorial representation is the core of many possible applications: from those in A.I. environment, to those related to relational databases. For A.I. applications, including the prototype definition of design Reasoners see the present chapter draws on [3] and presents a brief discussion of some applications concerning relational databases.
Our basic problem is how to handle a continuous feedback process between graphic-like data (typical of design work) and alphanumeric data (typical of database files). Actually, it seems that such feedback process is suitable to ensure efficient management of the building process from design, through production to maintenance. We are then posed with the problem of integrating the representation of BOs so as to efficiently comply with the following points:
i) keeping all the semantic content of design work at its different stages (from preliminary drawings to operational drawings);
ii) supporting all calculations (from metrical calculations to simulations of heat loss) made on model parameters instead of drawings;
iii) direct implementation of graphic information as:
a) information coming from C.A.D. processes (also interactive ones);
b) reading and recognition of existing drawing files by scanner;
iv) drafting design drawings of the implemented solutions and of their developments using special algorithms.

The following is a relational schema we have adopted that after testing proved to be particularly efficient and tough:
dwelling *(dwelling-id, room-id)* (1)
room *(room-id, wall-id)* (2)
wall *(wall-id, length, height, thickness)* (3)
adjacency *(wall-id, room-id1, room-id2)* (4)
succession *(wall-id1, room-id, wall-id)* (5)
direction *(wall-id, room-id, orientation)* (6)

Our variables are in italics, most variables are identifiers (indicated with the tag *-id*).

Relations (1) and (2) express the relationships existing in a room included in a dwelling and in a wall belonging to a room. Adjacency relationships hold between two rooms that are separated by (that are adjacent through) a wall. The relation of succession informs us of the dwelling's topological structure expressed by running along the perimeters of the rooms in a given direction (e.g. anticlockwise).





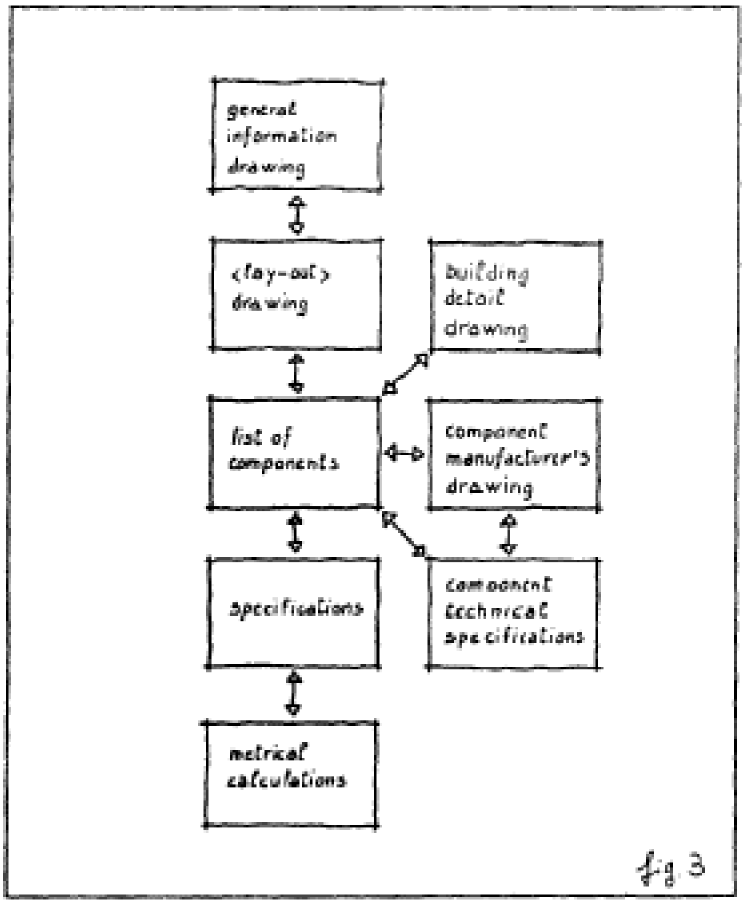
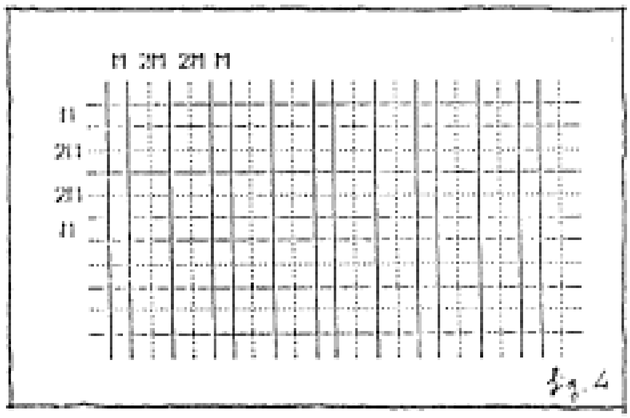
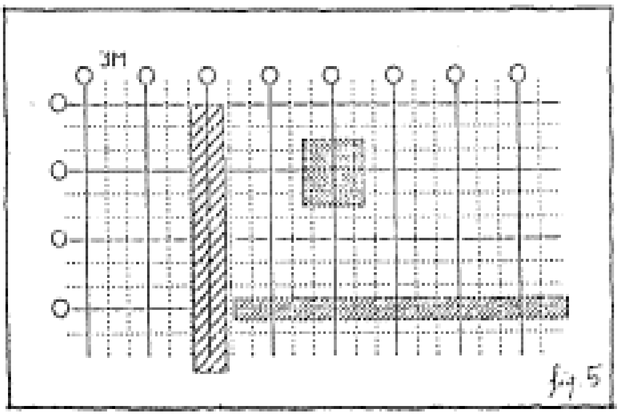


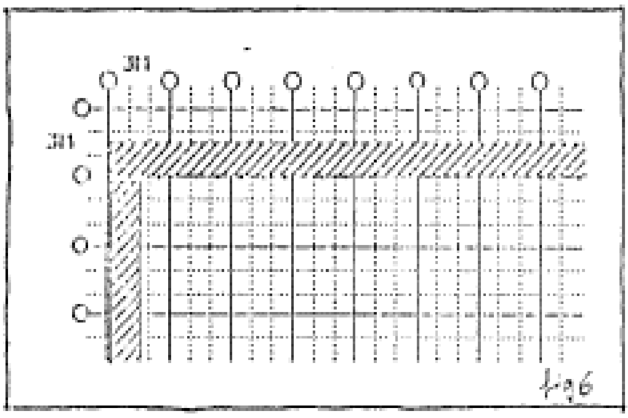
Figure 1. Conceptual data model

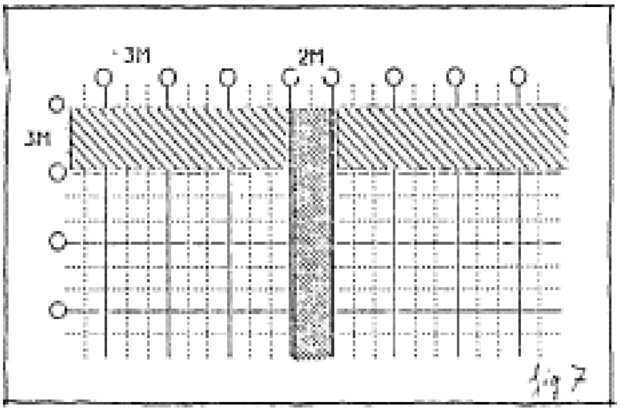
Figure 2. Architecture of the prototype

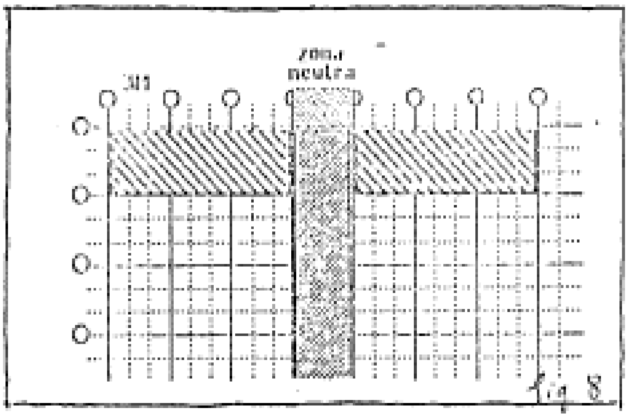
Figure 3. Communication rules of the project's "communication system"











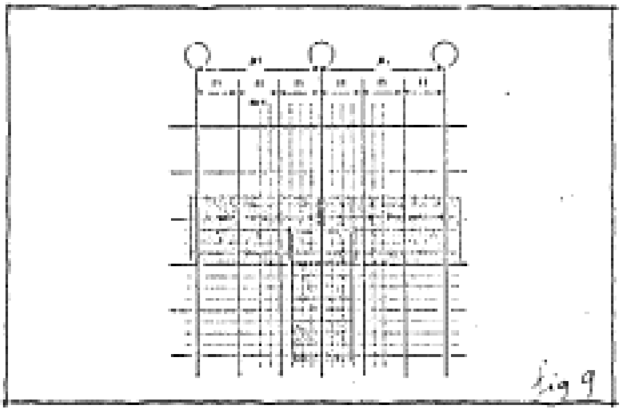


Figure 4. **n x (M + 2M + 2M)** multimodular grid, *Figure* 5. Example of a component axis coinciding with a line in a **n x 3M** multimodular grid 6. Example of a coordination plane face along a component's principal dimension coinciding with a line in a n x 3M multimodular grid. *Figure* 7. Example of two opposed coordination along a component's principal dimension coinciding with two in **a (n x 3M) + 2M** multimodular grid. *Figure* 8. Example of two opposed coordination planes of a component coinciding with two lines belonging to different modular and multimodular **n x 3M** grids separated by a non-modular space **(neutral zone).** *Figure* 9. Example of expansion of a grid towards a **M/4** (25 mm.) interval sub-modular reference grid with to components in simple symmetry.

The "*length*" variable and the "*direction*" relationship contain all the necessary information for the topological structures to be represented on coordinate systems.
The database is so structured as to contain the logical and consistency constraints for BOs, including:

i) a room cannot be adjacent to itself;
ii) congruence relations on the closure of polygons must hold;

The main feature of our representation is that it is "intrinsic", i.e. it holds all the topological and geometrical information on BOs without making any reference to coordinate systems. We will see later that coordinate systems should be used only for the handling of input-output algorithms. Our representation has the advantage of leading itself to easy connections with relational databases containing structured files on works, prices, technical information, specifications, etc.
With this goal in mind, the building project has been conceived as an information system. It has also been split into two subsystems: the decisional sub-system and the communication sub-system.
In this way, building design can be reduced to a form that is compatible with the structure of our relational model of BO which works as a decisional support. A systemic/semiologic analysis has been carried out where the communication sub-system is first synthetically considered as a set of elements meaningfully related to each other. It is then divided into significant sub-systems down to the level of elementary constituent parts and their relations. The communication sub-system can be divided into a grid of sub-codes, coordinated by an organization code and connected in such a way, that a series of sophisticated texts (documents) can be generated, each of which is directly or indirectly connected to the rest (see figure 3).
Any quantitative design work operation is to be carried out on the intrinsic representation rather than on its geometric image on the coordinate system. This gives the edge on the procedures currently employed. Quantitative operations are managed within the intrinsic representation. It is clear, however, that input and output project drawings must still be represented on coordinate systems. The following list of relations are needed for this purpose:

membership *(point-id, wall-id)* (7)
coordinates *(point-id, x, y)* (8)
ends *(wall-id, point-id)* (9)

Given the intrinsic structure, some algorithms are capable of directly producing a representation on a coordinate system by means of routines included in current graphic packages. They can also recognize models in graphic representations and store them into the database.
In this way, the model structures are easily linked both to the technological features of building components and to the procedures of calculating and editing technical documents and contracts. Moreover, it is thus possible to contextually access the graphical representations they determine.
This model so far described has been implemented on IBM AT hardware and Autocad graphic software at the Istituto di Edilizia of the Engineering Faculty, Ancona. Input-output, calculation and graphic procedures have also been developed. Figures 1 and 2 show the main features and the structure of our package that is made up of the following modules:

i) interactive graphic management
ii) input algorithms and management of intrinsic representation;
iii) relational database (works, prices, etc.);
iv) structural calculations;
v) metrical and assessment calculations;
vi)parameterized graphic representation of structures and architectural design.

Let us consider in this context the problem of developing a project starting from a wire-frame sketch showing only general information on rooms' dimensions and mutual position.
As we said earlier, an input algorithm stores the model of the BO into the database, the program then processes the model (not its graphic representation) and produces all the documentation required by project editing. However, in order to assess the consistency of room dimensions and of building components within a modular space grid, it is necessary to include in the database the relations that exist between the BO and those of the grid. Again, consistency control on the model makes certain that the model be adequate for these further developments.
Modular design may imply the following two basic modes [10]:

i) design over a grid;
ii) design with modular components

In the next chapter we will discuss the main rules to follow for the placing of components in modular spaces and the ways to tackle different problems according to the approaches mentioned above.

2. *Rules for placing components within modular spaces*

This chapter is devoted to modular space grids structured on suitable Modules. The main rules for the placing of components within the grid are described and two cases are dealt with (expansion and gaps) in which the topology of modular space is locally altered in accordance to special design requirements.
Let M be our reference unit (nominally 10-cm. long). It corresponds to the distance between the elements, of a set of parallel and equidistant planes (interval).
Two or three such sets of functually orthogonal planes make tip a grid that is called **'reference modular grid'**.
Among the n planes with **1M** interval and in accordance with the choices of the project operator and with mandatory or non-mandatory constraints, it is possible to distinguish the following:
i) a series of parallel planes with **n x M** interval (n = any natural number greater than 1);
ii) a series of parallel planes with a recurrent sequence whose interval measures **n x M; n' x M** (n = any natural number).
In i) the interval is always a multiple of the basic module M; in ii) at least one interval in the sequence is a multiple of the basic module M. These Planes make up a reference grid called **'reference multimodular grid'**.
Any building component may belong to either a point, a line, a surface or a space of the two- or three-dimension modular grid.

Let us assume as our basic operational conditions that our grid is coordinated on a coordinate system and that the wall-axis principle is respected. Our basic rule reads as follows:

1. The axis running along the main dimension of a component coincides with a line of the modular grid.

However, further rules may be expounded:

2. The face of coordination running along the main dimension of a component coincides with a line of the multimodular grid.

3. Two opposite faces of coordination running along the main dimension of a single component coincide with two lines of the multimodular grid. The distance between the lines measures n x M and is made to correspond to the component's coordination dimension. It can be said that the surface contained between two places of coordination of the component coincides with the surface contained between two lines or planes of the multimodular grid. This case defines net modular coordination;

4. Two opposite faces of coordination running along the main dimension of a single component coincide with two lines, separated by a gap in the multimodular grid. Such lines are the borders of two modular grids by a distance. Therefore the component fits into a neutral zone with at least one non-modular dimension.

Since it has been shown that some components have dimensions, that cannot be expressed in terms of modular or multimodular units, it is necessary to include a specific rule for the dimensioning of components in modular coordination, particularly in the basic situation of interaxial coordination, which could so meet every specific technological requirement.
Let us consider the example of coordination on a coordinate system: in a portion of space or surface at a distance x form a multimodular grid we can define as an 'expansion' of the grid towards a **sub-modular reference grid** built on a module measuring **M/4** (25 mm). As a consequence, x is multiple of the sub-module **M/4** and can be expressed by of n x M/4 where n is a natural number.
M/4 is small enough to correctly represent any technical dimension in terms of modules, thus providing the ground for adjusting individual elements' dimensions in conditions of physical and technical continuity and discontinuity among different or the same elements to be assembled. In particular, this rule makes possible the intersection of multimodular grid lines and planes and the finer adjustment of components within the multimodular grid.
The basic rule of the placing of components by means of axial coincidence or crossing may be further specified as follows:

i)position of simple or double symmetry with coordination planes which coincide with the coordination planes which coincide with the lines of the submodular grid and which are equal to n x M/4. Consequently the dimension in question equals 2 x (n x M/4);
ii) position of simple or double asymmetry with the lines of multimodular coordination in such a position that the dimensions in question equal n x M/4 + n' x M/4 where n and n' are natural numbers different from one another.

The next chapter will be devoted to the representation of modular space structures and to the representation of the relationships existing between components' dimensional features and the space parameter themselves.

3. *The contextual representation of modular space and building objects.*

We will now give the rules of coincidence between components' features (faces, axes, dimensions) and modular space parameters. Such rules may be employed both for design over a modular grid and for design with modular components. The former is characterized by the necessity to place components within the grid but it cannot always ensure the modularity of the spaces of use; the latter can ensure the modularity of the spaces of use but causes problems in singular points and at the level of components and modular space.

3.1. Let us introduce the relations that describe modular space structures and the rules of juxtaposition of components and grids. Let *interval-id* indicate the modular or multimodular structure of the coordination space (e.g., *interval-id* = 7 indicates a M+2M+2M multimodular structure).
Let *line-id* indicate any line belonging to the reference coordination plane. The relationship:

grid (*line-id, interval-id*) (10)

allows us to indicate if a generic line belongs to the family of lines that can be generated by the modular structure indicated by *interval-id.*
The relationship:

belongs to (*line-id, point-id, inclination*) (11)

defines the relationships between any line and its inclination and point of application.
We will use relation:

intersection (*line-id, line-id, point-id*) (12)

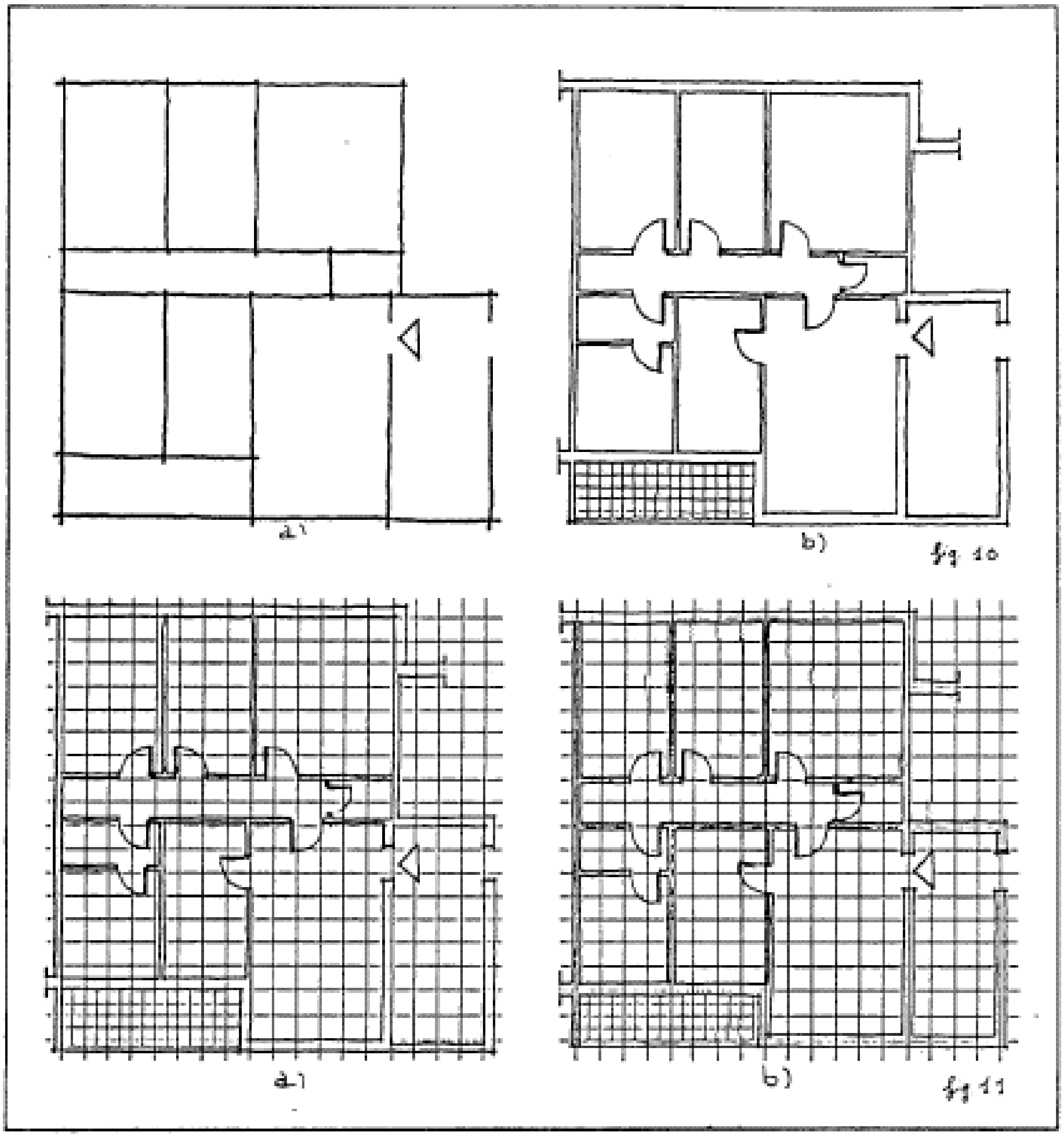
to find the point of intersection between two lines.
Also in this case we will omit the constraints binding the two relations together.
We have already seen how the structure of the coordination space can be locally expanded or deformed.
When a module is expanded towards a sub-module around an axis of space the following relation can be used:

expansion (*line-id, sub-module*) (13)

which, joined to relation:

grid (*line-id, sub-module*) (14)

yields two definitions of the lines belonging to a sub-modular space around a given axis.
Likewise, relation:



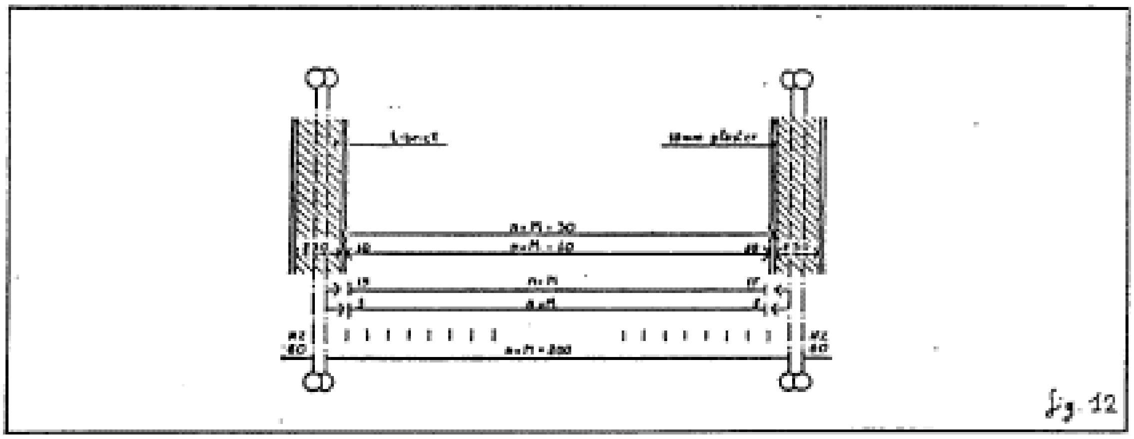


Figure 10. From a wire-frame sketch to project editing. *Figure* 11. From a given solution and a preferred coordination space to a 'deformed' solution. *Figure* 12. The modularity of the space between two walls implies tile 'deformation' of modular space grid structure.

gap (*line-id, gap*) (15)

can identify that portion of space where two lines of the grid show a hiatus measuring the value attributed to '*gap*'
The relations so far described allow us to describe the following operations on the modular space:

i) defining modular or multimodular grids;
ii) verifying whether a line or a set of lines belong to the grid;
iii) defining points as belonging to axes;
iv) individualising intersections between axes;
v) passing to a different scale by locally expanding the space;
vi) introducing topologically discontinuous structures.

3.2 As shown in chapter 1, the relations, from 1 to 9 alone can generate representations of BOs on a coordinate system according to the modes typical of technical drawing by means of a simple and efficient output algorithm. In fact, it is enough to introduce the coordinates of one point belonging to any wall. In order to comply with the last chapter's rule 1, the wall axis should be linked to a line:

axis (*wall-id, line-id*) (16)

Applying the other rules implies the definition of external limits or wall faces (and of the generic element):

face (*wall-id, line-id, x*) (17)
where *x* = length or thickness

These relations can indicate a component given its thickness, length and the lines that correspond to external surfaces in the drawing. To make things slightly more sophisticated (provided the notions of thickness and length are kept unambiguous, if this was not the case, further hypotheses would have to be introduced) variable *polylines-id* could take the place of variable *line-id* in order to describe more complex profiles. Then the following relation could be introduced:

Polyline (*polyline-id, point-id, point-id*) (18)

The notion of modular space expansion was needed to allow the analysis to pass to another scale, e.g., substituting polylines to lines in a drawing, as is often required by submodular reading. Our representation problem finally forces us to consider tolerances in juxtaposing components whose profiles can also be described using polylines. The relation:

juxtaposition (*x, y, tolerance-id*) (19)
where *x* and *y* may be either *polyline-id* or *line-id*

considers tolerances and allows us to represent them.
Our software can subsequently verify their consistency by reviewing them using the same tools as those employed by the output algorithm and introducing the dimensional modifications required by the adjustment of the preliminary schema to the requirements of the modular space. This algorithm uses a principle of 'deformation' which is linked to a

principle of minimality, i.e., it finds the nearest deformation to the starting solution (not forgetting that a representation was adopted which can be described in terms [3]). Figure 11 shows the process of deformation while figure 12 illustrates the problem of keeping the modularity of the distance between two walls by creating a gap in the modular space grid.

4. *Conclusions*

The paper contains an approach that allows us to use a relational database as a tool for the integrated management of an interactive design process. The aspects developed include assessment of consistency between topological and dimensional structures in a design sketch and development of the sketch in a modular coordination space.

5. *Bibliography*

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