F. Cella, S. Grimaz, F. Meroni, V. Petrini, R. Tomasoni
and G. Zonno:

# An application on Geographic Information Systems connected to Expert System

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# An application on Geographic Information Systems connected to Expert System

*Cella F. (*), Grimaz S. (**), Meroni F. (*),*
*Petrini V. (***), Tomasoni R. (*), Zonno G. (*)*

## 1. INTRODUCTION

The studies urban areas directed at the definition of seismic risk, raise the problem of the seismic vulnerability assessment of construction properties that require the estimation of the tendency to damage of a plurality of buildings. Very often one comes upon buildings that have been constructed in former epochs without the use of seismic codes and generally built in masonry. This leads to the search for procedures for vulnerability assessment, based on the rapid acquisition of information on existing buildings, which must furnish a sufficiently reliable assessment of the seismic damageability, generally without the possibility to refer to very sophisticated models.

In previous works, assessments of seismic vulnerability have been effected using surveys transferred on National Project for Seismic Prevention (GNDT) sheets (Zonno and Ducarme, eds, 1992) [1]. These works have been realized using expert systems in order to treat with the uncertainty of the data. However, the analyses that only refer to GNDT sheets, are limited to single buildings, ideationally understood as isolated. An alternative and maybe complementary attempt is to assess the vulnerability of buildings in a global structural context using Geographic Information Systems to mapping the urban system, integrated with the surveys transferred on GNDT sheets.

The main characteristics of the building and the structural context, indices of a major or minor damageability, have been individuated, but it is difficult to define a rapid procedure for the assessment of seismic vulnerability. The idea was to use an expert system to codify a basis of the presently acquired knowledge and to apply it automatically on the basis of the results obtained by processes of space analyses calculated by GIS.

On the basis of the data obtained with GNDT sheets (Fig. 1), the vulnerability of the building can be assessed independently from the structural context (intrinsic vulnerability). The availability of data on the space distribution of the adjoining buildings permits an assessment on the effective vulnerability that takes into account the influence of the structural context.

(*) *Istituto di Ricerca sul Rischio Sismico - CNR*
*Via Ampère 56 - 20131 Milano - Italia*
(**) *Dipartimento di Georisorse e Territorio - Facoltà di Ingegneria*
*Università degli Studi di Udine; Via Cotonificio 114 - 33100 Udine - Italia*
(***) *Dipartimento di Ingegneria Strutturale - Politecnico di Milano;*
*Piazza Leonardo da Vinci 32 - 20133 Milano - Italia*


Fig. 1 - Buildings' map of the Venzone's old town. The circled numbers indicate the existing regular sub-blocks. The bold drawn buildings show where the effective vulnerability has been calculated.

With relation to other works effected on the argument, the proposed system automatically assesses a large quantity of geocoded data either in geometry and in the structure of the components. In particular, in this work the seismic vulnerability assessment of the buildings is effected through the Geographic Information Systems PC Arc-Info connected with the Expert System Shell Nexpert Object, starting from the methods used by the GNDT of the National Council for Research (CNR) (Benedetti and Petrini, 1984; Baldi and Corsanego, 1987) [2] [3] and integrating the effects of anisotropics of the structural behaviour and context (Grimaz, 1992-93) [4] [5].

## 2. SEISMIC VULNERABILITY ASSESSMENT

The assessment method of the GNDT is based on the analysis of a series of information on the characteristics of the structural elements of the building that are collected by means of sheets and that permit to assess the vulnerability with regard to a certain number of parameters that are representative for the predisposition of masonry buildings to suffer damage caused by seismic events. Some of them refer to the behaviour of the structure and non-structure elements, others to the behaviour of the total constructive organism. Eleven parameters have been individuated:

1 - type and organization of the resisting system
2 - quality of the resisting system
3 - conventional safety factor
4 - position of the building and foundations
5 - diaphragms
6 - plan
7 - elevation
8 - maximum distance between parallel walls
9 - roof
10 - non-structural elements
11 - damage and decay

Once the vulnerability rating (corresponding to one of the four classes defined per each parameter) [2] and the weights corresponding to the parameters have been assigned, a vulnerability index is determined as a summation of the ratings multiplied by the respective weights.

$$i.v. = \Sigma_i \, p_i \times w_i \qquad (1)$$

This index represents the vulnerability of the building understood as an extract from the structural context and referred to the direction of major damageability. In order to take into account the fact that generally a building presents a different damageability due to the shaking direction, in a first approximation, the complete vulnerability development can be represented by an oriented ellipse (Grimaz, 1992) [4] having axes proportional to the vulnerability indices, always assessed with the relation (1), for both principal directions *X* and *Y*.

This is the definition for an ellipse of intrinsic vulnerability **U** which expresses the vulnerability of a building understood as isolated or extracted from a structural context with a variation of the shaking direction. The axis of the ellipse in the direction k is determined as follows:

$$U_k = \Sigma_i \, p_{ik} \times w_i \qquad K = x,y \tag{2}$$

In order to take into account the influence of the structural context with the scope to determine the effective vulnerability of the building, one has to individuate a series of factors of the structural context to which the modification of the damageability of the building is attributed, passing from the intrinsic condition to the effective one. The vulnerability ellipse **V** is therefore obtained by the deformation of the intrinsic ellipse caused by the presence of the factors of context **f**.

$$\mathbf{V} = \beta \times \mathbf{U} \tag{3}$$

where $\beta$ is the mentioned function of deformation and is defined as follows (Grimaz, 1993) [5]:

$$\beta(\beta_x,\beta_y) = (\mathbf{1} + \delta\beta) = (\mathbf{1} + \Sigma_j \mathbf{f}_j) \tag{4}$$

In the case of an isolated building, where no context factor is activated, $\beta$ assumes the value 1, and the effective vulnerability ellipse corresponds with the intrinsic one.

In case of a building that is part of a set of contiguous buildings, in the present work, the following effects are considerated as factors of context or deformation:

$\mathbf{f_{cl}}$ local effects of structural context
$\mathbf{f_{cs}}$ global effects of structural context
$\mathbf{f_{ds}}$ effects due to a structural inhomogeneity

so that the relation (4) assumes the form

$$\beta(\beta_x,\beta_y) = (1 + \mathbf{f_{cl}} + \mathbf{f_{cs}} + \mathbf{f_{ds}}) \tag{5}$$

The first factor $\mathbf{f_{cl}}$ is bound to the geometrical properties of the building and the neighbour structures. The assessment of the effects is led back to the definition of indices of form irregularity calculated on the basis of information obtained by the GNDT sheets.

The second factor $\mathbf{f_{cs}}$ is related to the position of the building in the structural context and takes into account changes on the in plane wall behaviour and the dynamic effects of amplification or reduction of the deformations with regard to the intrinsic condition.

The synthesis assessment of these effects on the building is led back to the definition of cases of morphological-structural conditions of context; thus, the procedures for the individuation of the positions of the generic building in the sub-block are defined. To every position a percentual rating of improvement or deterioration is then attributed due to the influence of the structural context.

The third factor $\mathbf{f_{ds}}$ takes into account the dynamic effects of interaction caused by big differences in the dynamic characteristics, the material or the presence of structural discontinuity. This factor also makes part of the information furnished by GNDT sheets.

The problem, however, arises in more important terms in the assignment of the positions where the information source of the sheets must be integrated with a map of the urban environment. Connecting the alphanumerical information with the graphic one, it is possible to reconstruct geometrical properties on which the positions can then be individuated.

## 3 - DEFINITION OF THE POSITIONS

In the context of the present work it has been considered reasonable to introduce, in the following, a series of definitions for a better comprehension of the topic:

***length***: dimension referred to the direction of the street front

***width***: dimension referred to the right-angled direction of the street front

***block***: total complex of the buildings at contact

***regular sub-block***: a part of a block formed by contiguous buildings, aligned along a principal direction without distinct interruptions between:

***line of continuos buildings*** if they develop for a length of more than 2.5-3.0 times the medium height of the considered buildings

***contiguous buildings*** line of contiguous buildings with a total length of less than 2.5 of hits heights, if the development is inferior or if there are no interruptions,

***adjacent buildings*** in all other cases;

***irregular sub-blocks***: if no predominant alignment can be individuated.

The interruptions of the regular sub-blocks can be distinguished between:

***break due to change in axis translation***: when the distance between the longitudinal median axes of two series of contiguous and aligned buildings is comparable or superior to the mean width of the buildings.

***break due change in axis direction***: when the angle formed by the longitudinal median axes of two series of contiguous and aligned buildings is greater than 45 degree.

***break due to changes in structural properties***: presence of separation joints effective for seismic purposes; lowering of the roof line above 2/3 (e.g. changing from three floors to one); presence of big opening ways of a height equal to at least half of the building height; presence of a building with a big axis translation of the principal body or that represents a large narrowing of the map continuity (e.g. medium length above 2/3).

Finally it can be defined:

***long building***: a building that develops along a direction with a length in plan greater than 2.5-3.0 times its mean height.

## 4. ASSIGNMENT OF THE POSITIONS

The approach used for the assignment of the positions is the subdivision of the analysis in more cascade levels: at first the investigation of the whole environment individuating the structural blocks, a second that inside the blocks individuates the block portions that are comparable to regular or irregular sub-blocks and that permit to define the zones of intersection or joint between these, a third that defines the position assumed by the building inside the sub-blocks. At each level *"candidates at certain positions"* are defined and then *"elected"* or not in the level of subordinated analysis.

The procedure of assignment, even if the concept is simple, develops in different stages connected among each others that render the objective assignment of the position rather difficult for the operator, also in consideration of the large quantity of cases. Therefore, it has been considered necessary to develop, by this work, an automatic assignment of the positions of the single buildings.

This process is composed of the following phases:

- acquisition and organization of alphanumerical and graphic information;
- recognition of the regular and non regulars sub-blocks;
- individuation of the interruptions and joints between regular sub-blocks;
- location of the building and topology evaluation of the sub-block to which it belongs;
- application of the rules for the assignment of the building position.

### 4.1 RULES FOR THE ASSIGNMENT OF THE POSITIONS

The assignment of the position is led separately for each of the two principal directions of the building that are congruent with the *X* and *Y* axes used in the compilation of the GNDT sheet. On the basis of the typology of the sub-block of origin, the following cases appear: regular sub-blocks and irregular sub-blocks.

**Regular sub-blocks**

BUILDINGS AT CONTACT

Let *N-building* **N** the bigger building at contact
Let *Af-building* **Af** the smaller building at contact

ADJACENT BUILDINGS

Let *Af-building* **Af** in any case

LINE OF CONTINUOS BUILDINGS

Let *A-building* **Ap**, **Ae** or **Aa** depending whether the building is interested in breaks due to discontinuity in plan or in elevation.

The following *A-buildings* have been defined:

**Ap** *A-building in plan*
*strong axis translation in plan*
*connection between line of continuos buildings with axis translation*
**Ae** *A-building in elevation*
*large opening*
*heavy lowering*
**Aa** *A-building in angle*
*angle position*

Let *I-building* **I** if the building is not in an *A-building* and there are contacts on both sides of the building in the direction of the line of continuos buildings to which it belongs.
Let *E-building* **E** if the building in not in an *A-building* and the building only has one contact in the direction of the line of continuos buildings to which it belongs.

Let *N-building* **N** if the building is not influenced by the context

LONG BUILDINGS

They are considered as *N-buildings* **N** in the longitudinal direction no matter whether they are in contact, adjacent or belonging to a line of continuos buildings.

**Irregular sub-blocks**

The *position* is defined *irregular* and the influence is assessed each time by a detailed analysis of the structural situation of the context.

To the irregularity form indices a percentual rating $\mathbf{f_{cl}}$ is associated, whereas there is a percentual rating $\mathbf{f_{cs}}$ for every position. By the alphanumerical data of the sheets, the possible activation of structural inhomogeneity factors is assessed; to these factors, a further percentual rating $\mathbf{f_{ds}}$ is associated. Thus, for both principal directions $\beta$ is determined by (5) and the effective vulnerability is defined by (2).

**Arc Attribute Table**

| FNODE# | TNODE# | LPOLY# | RPOLY# | LENGHT | ARC# | USER-ID |
|---|---|---|---|---|---|---|
| 161 | 152 | 1 | 73 | 13.22758 | 211 | 173 |
| 152 | 179 | 71 | 73 | 17.59564 | 237 | 172 |
| 184 | 161 | 76 | 73 | 14.45697 | 244 | 168 |
| 179 | 184 | 1 | 73 | 12.75478 | 249 | 111 |
| 187 | 172 | 81 | 80 | 11.08439 | 250 | 158 |

where:
FNODE# : arc starting node internal number (From Node);
TNODE# : arc ending node internal number (To Node);
LPOLY# : internal number polygon located at left of the arc (Left Poly);
RPOLY# : internal number polygon located at right of the arc (Right Poly);
LENGHT : arc lenght in coverage units;
ARC# : arc internal number;
USER-ID : arc User identifier;

**Polygon Attribute Table**

| AREA | PERIMETER | POLY# | USER-ID |
|---|---|---|---|
| 89.23989 | 48.35342 | 80 | 3 |
| 57.17066 | 35.94327 | 76 | 4 |
| 205.0334 | 58.03497 | 73 | 5 |
| 109.2417 | 48.90976 | 71 | 6 |
| 100.5127 | 43.46296 | 67 | 7 |

where:
AREA : area of polygon in coverge units;
PERIMETER : perimeter of polygon in coverge units;
POLY# : polygon internal number;
USER-ID : polygon User identifier;

Fig. 2 - Standard format of the tables AAT and PAT of a Arc/Info coverage. In the AAT file, every record describes a side of the polygon. Every record of the PAT file represents a polygon that is inherent to a building. The dashed records are related to the polygon number 73.

## 4. ARC-INFO and NEXPERT

Arc/Info and Nexpert are commonly used by many research groups in the National Group for Seismic Prevention (GNDT); integrations and completions inside the GNDT are possible. Both are open systems, that is, they permit the full integration of external routines into their main kernels. Arc/Info allows to use an internal command language SML (Simple Macro Language) [6], whereas Nexpert can be integrated into any program written in C language [7]; an important fact is that either PC Arc/Info and Nexpert have access to a common data base which in the present case is dBASE III+.

The Expert System Shell Nexpert uses an object-oriented data structure, by which it is possible to assign complex relationships between data. GIS Arc-Info, on the other hand, is a means for the storage and representation of spatially georeferenced information; in Arc/Info, every spatial feature has a unique geographic location specified by its *X* and *Y* coordinates; it has a unique identification number, and it is connected to descriptive data in a data base.

The data transfer from Arc/Info to Nexpert is fulfilled by PC Arc/Info Rev. 3.4D, whose feature attribute tables use dBASE III format. Nexpert can directly read and write dBASE III files, so that any number of items for any number of records can be read in or written out of Nexpert in this way. The connection between Arc/Info and Nexpert is performed at data level, that is, there is a one-to-one association between tables, records, and items in Arc/Info, and classes, objects, and properties in Nexpert.

## 5. DESCRIPTION OF THE EXPERT SYSTEM

### 5.1 - GIS preprocessing

The territorial information has been digitized from the photogrammetric survey in scale 1/2000 of the Venzone old town in Autocad format. The engineering-structural data and those of damage indicated on the vulnerability sheets of the 1st e 2nd level of the GNDT are transferred to the Geographic Information System Arc/Info. The map with the plan of buildings of the whole municipality has been imported into the software using the Autocad DXF format. This digitalization, after having been filtered and cleaned from the imprecisions of acquisition, has thus assumed the form of Arc/Info coverage which has produced a polygonal topology; by this instrument Arc/Info associates table information to the geocoded information. For this purpose, the software generates, among others, two tables in format dBASE III+ which describe the relationships between the arcs (AAT file - Arc Attribute Table) and the polygons coverage (PAT file - Polygon Attribute Table, see Fig. 2).

After a kind of standard fields, that have been created by Arc/Info itself, we have added to these tables some descriptive attributes referring to lines (sides of the buildings) and to polygons (buildings) in order to fit the necessary graphic information for an automatic classification.

The relation between the data base of the GNDT sheets and the map reference is realized with the following additional fields: AGGR = sub-block number and SCHEDA = number of GNDT sheet (referring to the building, see Fig. 4).

The data of the GNDT sheets are then translated in dBASE III+ by means of eight tables; each of these tables contains the sections in which the vulnerability sheet of the 1st level has been subdivided; furthermore there are two tables that respectively contain the data of the 2nd level sheet for masonry building and the results of the intrinsic vulnerability index calculated inside the GIS with previously available programs. In the following is shown the data base files structure:

1st level GNDT sheet

| | |
|---|---|
| SEZ_1.DBF: | sheet reference data |
| SEZ_2.DBF: | building localization |
| SEZ_3.DBF: | metrical data |
| SEZ_4.DBF: | use and purpose of the building |
| SEZ_5.DBF: | building age |
| SEZ_6.DBF: | degrade level |
| SEZ_7.DBF: | structural typology |
| SEZ_8.DBF: | damage level |

2nd level GNDT sheet (masonry only)

SEZ_MU.DBF: evaluation elements
SEZ_VUL.DBF: calculated vulnerability index

It has been necessary to indicate the sides of the buildings that are located on the street front, univocally numbered. This operation is important for the automatic recognition of a line of continuos buildings and of the positions of the buildings inside the line. In this step, also the orientations of the street fronts with respect to the cartesian directions *X* and *Y*, that have clearly been individuated on the whole town, are assigned. This solution is necessary for the analysis of the effective vulnerability of buildings within a structural context, along the two directions *X* and *Y*. As it can be seen on Fig. 3, this information is stored in the attribute fields of the AAT file (fields FRONTE_S and ORIEN).

**AAT file structure - VENZONE Coverage**

| | |
|---|---|
| FNODE#<br>TNODE#<br>LPOLY#<br>RPOLY#<br>LENGTH<br>ARC#<br>USER-ID | : AAT standard items |
| FRONTE_S | : number of the street front |
| ORIEN | : orientation of the street front side |

Fig. 3 - Format of the AAT of the coverage Venzone. In the last two fields the attributes of the street front sides are stored.

### 5.2 - Arc/Info processing.

The polygon topology is thus completed by the information referring to the vulnerability sheet of the buildings and permits to gain information on the structural context (Fig. 1). The buildings that haven't the GNDT vulnerability sheet are eliminated from the coverage in order to obtain a sub-set of buildings (bold in Fig. 1). Furthermore, the following process does not take into account the buildings without information on the context of which they make part (e.g. the building n° 64, sub-block n° 8 and the building n° 71,72 and 73, sub-block n° 13).

The attribute fields necessary for the individuation of the line of continuos buildings and the position of the buildings have been appended to the PAT of the coverage *Edifici* for an easy connection with the expert system. Some information from the GNDT sheets has been included, as it is necessary for the calculation of the effective vulnerability of every structure: e.g. the building height calculated from section 3 of the sheet, the predominant structural typology of the vertical structures syntethized in 6 main groups, taken from section 7 of the sheet and the $\tau_k$ value which is the characteristic resistance of masonry, from the 2nd level sheet.

The structure of the PAT of Arc/Info allows to gain precious information which is very useful in the analysis of the global context of the buildings, such as:

case 1 - the position of the building by means of the polygon centroid which describes it;

case 2 - the adjacent polygons of every building by the *User_ID* of the adjoining buildings;

case 3 - the lengths, the orientation and the *User_ID* of the sides on the street front for each building.

**PAT file structure - VENZONE Coverage**

| | | |
|---|---|---|
| | AREA | : PAT standard items |
| | PERIMETER | |
| | POLY# | |
| | USER-ID | |
| | SCHEDA | : GNDT sheet number |
| | AGGR | : sub-block number |
| INPUT DATA | POL_ADD1 | : User-ID of the 1st adjoining polygon |
| | POL_ADD2 | : User-ID of the 2nd adjoining polygon |
| | POL_ADD3 | : User-ID of the 3th adjoining polygon |
| | POL_ADD4 | : User-ID of the 4th adjoining polygon |
| | POL_ADD5 | : User-ID of the 5th adjoining polygon |
| | POL_ADD6 | : User-ID of the 6th adjoining polygon |
| | ALTEZZA | : building height |
| | TIPOL | : building structural typology |
| | MU47 | : $\tau_k$ of the building |
| | X_COORD | : X coordinate of the polygon centroid |
| | Y_COORD | : Y coordinate of the polygon centroid |
| | FRONTE_SX | : street front number along X direction |
| | FRONTE_SY | : street front number along Y direction |
| | LUNG_FSX | : street front length along X direction |
| | LUNG_FSY | : street front length along Y direction |
| RESULTS | SCH_X | : line of continous buildings number along X direction |
| | SCH_Y | : line of continous buildings number along Y direction |
| | POSIZ_X | : position of the building along X direction |
| | POSIZ_Y | : position of the building along Y direction |
| | VIX | : intrinsic vulnerability in X direction |
| | VIY | : intrinsic vulnerability in y direction |
| | VEX | : effective vulnerability in X direction |
| | VEY | : effective vulnerability in Y direction |

Fig. 4 - Format of the PAT of the coverage Venzone. The first four fields are generated inside the GIS Arc/Info. The following items have been taken from the expert system. The last items contain the results from the automatic classification.

This information is directly obtained by Arc/Info commands as in case 1, or by procedures written in SML in cases 2 and 3. The information is then saved in appropriate fields that are already present in the PAT.

In particular, the centroid of every polygon is saved in the fields X_COORD and Y_COORD, expressed in UTM coordinate. The adjoining buildings are saved in previously created fields such as POL_ADD1 to POL_ADD6, while the information of the arcs (case 3) for both reference directions is saved in the fields FRONTE_SX, FRONTE_SY and LUNG_FSX, LUNG_FSY (see Fig. 4).

Other data, as the area and the perimeter of every polygon are automatically calculated by the GIS.

### 5.3 - Data import to Nexpert Object

The connection between the GIS and the expert system developed with the Nexpert Object shell has been realized by sharing the data structures, initially implemented inside Arc/Info. This connection is based on an association between tables, records and items of Arc/Info which in Nexpert respectively become classes, objects and properties. In this phase, the relational model of spatial data used by the GIS is connected with the object-oriented data structure used by the expert system.

**PAT file - VENZONE coverage (Sub-block n. 18)**

| AREA | PERIMETER | POLY# | USER-ID | SCHEDA | AGGR | ALTEZZA | TIPOL |
|---|---|---|---|---|---|---|---|
| 84.7522 | 37.5635 | 86 | 1 | 85 | 18 | 9.8 | G1 |
| 77.8457 | 36.3791 | 81 | 2 | 86 | 18 | 9.8 | G1 |
| 89.2399 | 48.3534 | 80 | 3 | 87 | 18 | 9.7 | G1 |
| 57.1707 | 35.9433 | 76 | 4 | 88 | 18 | 9.6 | G1 |
| 205.0334 | 58.0350 | 73 | 5 | 89 | 18 | 10.4 | G1 |
| 109.2417 | 48.9098 | 71 | 6 | 90 | 18 | 9.5 | G1 |
| 100.5127 | 43.4630 | 67 | 7 | 91 | 18 | 9.5 | G1 |
| 177.0926 | 64.8319 | 68 | 8 | 92 | 18 | 9.2 | G2 |
| 91.5360 | 41.7239 | 72 | 9 | 93 | 18 | 9.1 | G2 |

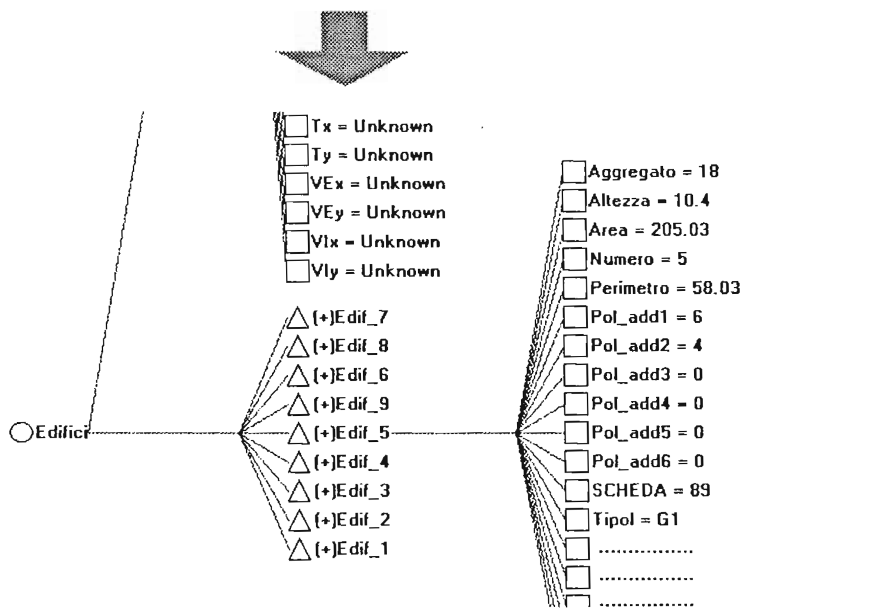


Fig. 5 - Porting data from Arc/Info to Nexpert: record n° 73 (User-Id = 5, Sheet = 89) of the PAT imported into Nexpert becomes the object *Edif_5* and inherits the properties of the class *Edifici*.

Nexpert Object directly reads and writes the Feature Attribute Table of Arc/Info, and for every record of the table it creates a new spatial object inside the data structure of the expert system. In figure 5, it can be seen how each PAT element (i.e. record means building) is transformed into an object in the working memory of Nexpert belonging to the class *Edifici*.

The name of the object is dynamically created by the *User_ID* of Arc/Info associated to the building. Every item of this record containing the properties (Area, Perimeter, Height, Adjoining Buildings, Structural Typology, etc.) is loaded in an attribute of the object itself. From the class *Edifici* one also inherits the methods for the calculation of some additional properties, which are necessary for the identification process of the line of continuos buildings.

Later on, the capacity of Nexpert to carry out inferential reasoning is used to activate the assessments on the structures of imported objects, reaching the conclusions requested by the analysis. When the inferential process is terminated, the *property slots* of the objects containing the elaboration results are transferred as new items to Arc/Info for the representation of the results in graphic form.

### 5.4 - Evaluation rules of a line of continuos buildings

All rules applied to the available data are the knowledge base of the expert system. It selects inside the single sub-blocks the line of continuos buildings with the relative orientation and assigns also the position to every building, as for example *I-Building*, *E-Building*, *A-Building* etc.

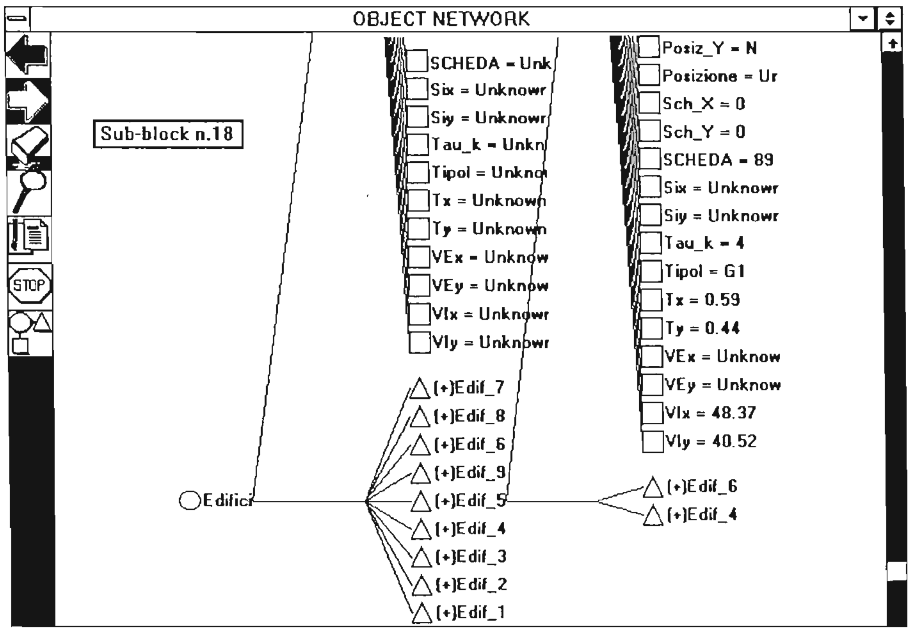


Fig. 6 - Relationships between the objects of the class *Edifici* in the environment Nexpert Object. The objects *Edif_4* and *Edif_6* (sub-block n° 18) result adjacent to the building *Edif_5*, as indicated by the links.

The individuation of the line of continuos buildings is composed by an inferential process that operates on a structure of dynamically created objects inside Nexpert. The adjoining relations between the buildings of the sub-block are in such a dynamic structure and are transformed following the relationship and represented by logical links between the objects of the class *Edifici* (Fig. 6).

The inferential process of the expert system starts from an initial number of buildings grouped in function of the street front. The properties of the street front sides of the buildings, FRONTE_SX and FRONTE_SY, are transformed in logical links between the objects that describe them and the classes that individuate the single street fronts (Fig. 7).

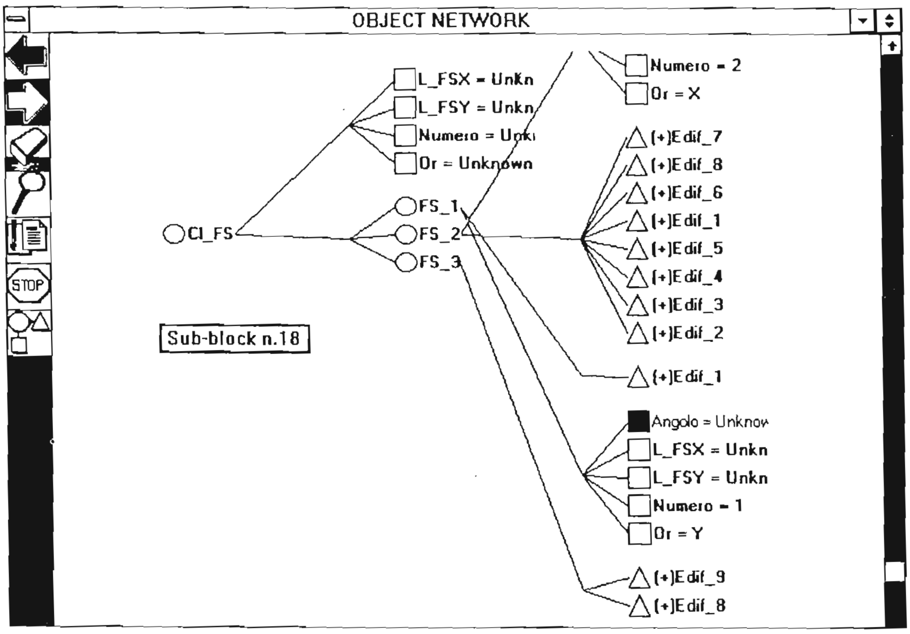


Fig. 7 - Connection between Class and Object for the description of the street fronts. The classes *FS_1*, *FS_2* and *FS_3* contain the buildings belonging to three different street fronts individuated on sub-block n° 18.

These groups are a first subdivision of the buildings in classes of *candidates of a line of continuos buildings*, on the basis of which the subsequent analyses are made.

In a second step the detection of the interruptions in the origin regular sub-blocks introduces furthermore *candidates of a line of continuos buildings.* Then the following *A-buildings* are recognized and assigned:

Ae : break due to discontinuity elevation ($\Delta$ height > 2 floors) between adjacent buildings;

Ap : break due to axis translation in plan of two series of contiguous buildings;

Ape: composite break with overlapping of the previous effects.

The previous cases are only recognized by the use of the features of the polygon topology: centroid coordinates, area, perimeter and street fronts. Furthermore, the *long buildings* in the sub-block are detected; this is sufficient condition for the independence of the single building from the structural context.

The characteristics individuated in this way, are saved as new attributes of the objects as a link between them.

All *candidates of a line of continuos buildings* that have previously been individuated are examined again in function of their dimensions, in order to check whether the conditions necessary for the existence of the line of continuos buildings are fulfilled. If the lines of continuos buildings are evaluated *true* then they are confirmed by a progressive number and its relative orientation. The remaining buildings are grouped in the *contact* or *adjacent building classes* regarding the existing breaks between the adjoining lines.

On the last operation we have marked the positions of the buildings inside the line of continuos buildings along both directions of analysis. The positions *I-Building, E-Building* and finally also the *Aa-buildings* are assigned..

### 5.5 - Evaluation rules of effective vulnerability

The revision of the vulnerability values on the structural context is effected on the basis of a set of rules. For each building belonging to a line of continuos buildings the expert system assesses the contribution of the various factors that make the relation (5). A subdivision in three classes of the characteristical factors of the structural context can be represented as follows:

1 - *Local* context effects.

$\mathbf{f_1}$ : lengthening of the building;

$\mathbf{f_2}$ : plan irregularity of the building;

$\mathbf{f_3}$ : lowering of the roof line ( 1 floor < $\Delta$ height < 2 floors) of a line of continuos buildings.

2 - *Global* context effects.

The position **E**, **I**, $\mathbf{A_a}$, $\mathbf{A_p}$, $\mathbf{A_e}$ and $\mathbf{A_f}$ as previously defined.

3 - *Structural inhomogeneities* of the materials for contiguous buildings.

D: structural typology divided in six classes;

$\tau_k$: characteristic resistance, only if the structural typology D is different.

The information relating to the global context effects has already been estimated by the expert system during the assessment of the positions of the buildings. The local context effects and the ones of structural inhomogeneity, however, are directly determined by the information in the feature attribute table previously described.

Furthermore the $\mathbf{f_3}$ factor is assessed by the comparison between the heights of the adjoining buildings with the one in examination. At the actual stage of development of the prototype the characteristics $\mathbf{f_1}$ and $\mathbf{f_2}$ are not considered.

All factors of the structural context are associated to weights that have been estimated in a previous work [8], and the summation of their contribution, either positive or negative, assigns the effective vulnerability value of the structural context. The values of the weights of the various factors used in this work are indicated (see Fig. 8). For every building, the effective vulnerability factors are calculated and shown by a dialog box in interactive way. These values are also saved in the fields VE_X and VE_Y of the PAT and are so ready for a graphic visualization by Arc/Info.

| LOCAL CONTEXT | | | GLOBAL CONTEXT | | | | | | STRUCTURAL INHOMOGEN. |
|---|---|---|---|---|---|---|---|---|---|
| $f_1$ | $f_2$ | $f_3$ | E | I | $A_a$ | $A_p$ | $A_e$ | $A_f$ | D |
| 0.18 | 0.15 | 0.09 | 0.12 | -0.33 | 0.24 | 0.03 | 0.09 | -0.48 | 0.09 |

Fig. 8 - The used weights of the effects $\mathbf{f_j}$ from the relation (4).

### 5.6 - Results display

At the end of the analyses effected with the expert system realized with Nexpert, the results saved in the attribute fields of the coverage are displayed by the graphic module of the Arc/Info: ARCPLOT.

This tool allows furthermore to make queries on the data relating to the coverage of the town investigated. It is also possible to display, in addition to the intrinsic and effective vulnerability values, the line of continuos buildings identified on the town map and the positions of the single buildings in function of the direction considered.

The vulnerability values in the two directions *X* and *Y* are visualized with the sketching of the *vulnerability ellipses* [5] by a user SML macro or by colour undercoats of the polygons that represent the plan of the buildings.

### 6 - RESULT DISCUSSION

The first group of rules described in paragraph 5.4 analyze the coverage containing the data of the historical centre of Venzone and identify the lines of continuous buildings of the thirteen sub-blocks considered as well as the position of the single buildings in the analysis directions.

In figure 9, the different lines of continuous buildings that have been individuated are shown. The fourteen non-sketched buildings are the following cases: isolated buildings or buildings with an unknown context (e.g. building n° 19), buildings that are not make a line of continuous buildings for dimensional reasons (e.g. building 52, 53), nearby buildings (e.g. building n° 93) and the buildings of interruption (e.g. building n° 61). A total twenty-five lines of continuous buildings has been individuated. In the low left corner of the figure, the cartesian references axes for the assignment of the absolute analysis orientation are indicated. The lines of continuous buildings identified on the map are univocally assigned; in the same way, the positions of the single building are indicated along two directions. The criterion of the choice of direction is critical because it is connected to the operator assignment of the street fronts direction (paragraph 5.1) that are the initial candidates of a line of continuous buildings (paragraph 5.4). Note that the polygons without label are courtyards at the inside of the buildings.

In figure 10, there is a table of the results illustrated on the map described before. The fields SCH_X and SCH_Y contain the progressive numbers of the lines of continuous buildings that are present at the inside of every sub-block. The position of the buildings are indicated in the fields POSIZ_X and POSIZ_Y. The position of every building is contemporary assigned for both directions whereas the number of the line of continuous buildings is indicated only in the direction in which the line is oriented; for all other cases the value zero is assigned.

We shall examine in detail the results concerning sub-block n° 3. A total of 3 line of continuous buildings as been individuated: the first one comprises building n° 24 and 23 in direction *Y*; the second one is composed of buildings n° 23, 27 and 47 in direction *X*; the last one is composed of buildings n° 25 and 26 with orientation *Y*. Note that building n° 24 is a *long building* as shown by the position **N** in both directions. The building n° 23 results an angle building **Aa** due to the intersection of the lines of continuous buildings n° 1 and n° 2. Finally, building n° 61 does not result inserted in any line (*building at contact* signed by **C**) as it is the interruption for axis translation in plan with respect to building n° 25. On the opposite side, for building n° 47, the position **Af** is assigned in direction *Y*.

The knowledge base described in paragraph 5.5 uses the information previously showed for the calculation of the vulnerability indices. The obtained results are indicated in the last four columns of figure 10: VUL_Int_X and VUL_Int_Y concerning the intrinsic vulnerability and VUL_Eff_X and VUL_Eff_Y for the effective one. On the whole large variations of the vulnerability index can be noted with the maximum increment of 18.7 (42%) in *X* direction and 15.4 (42%) in *Y* direction for building n° 4. The reduction of the effective vulnerability index reaches maximum values of 20.8 (33%) in *X* direction for building n° 27 and 24.5 (48%) in direction *Y* for building n° 47.

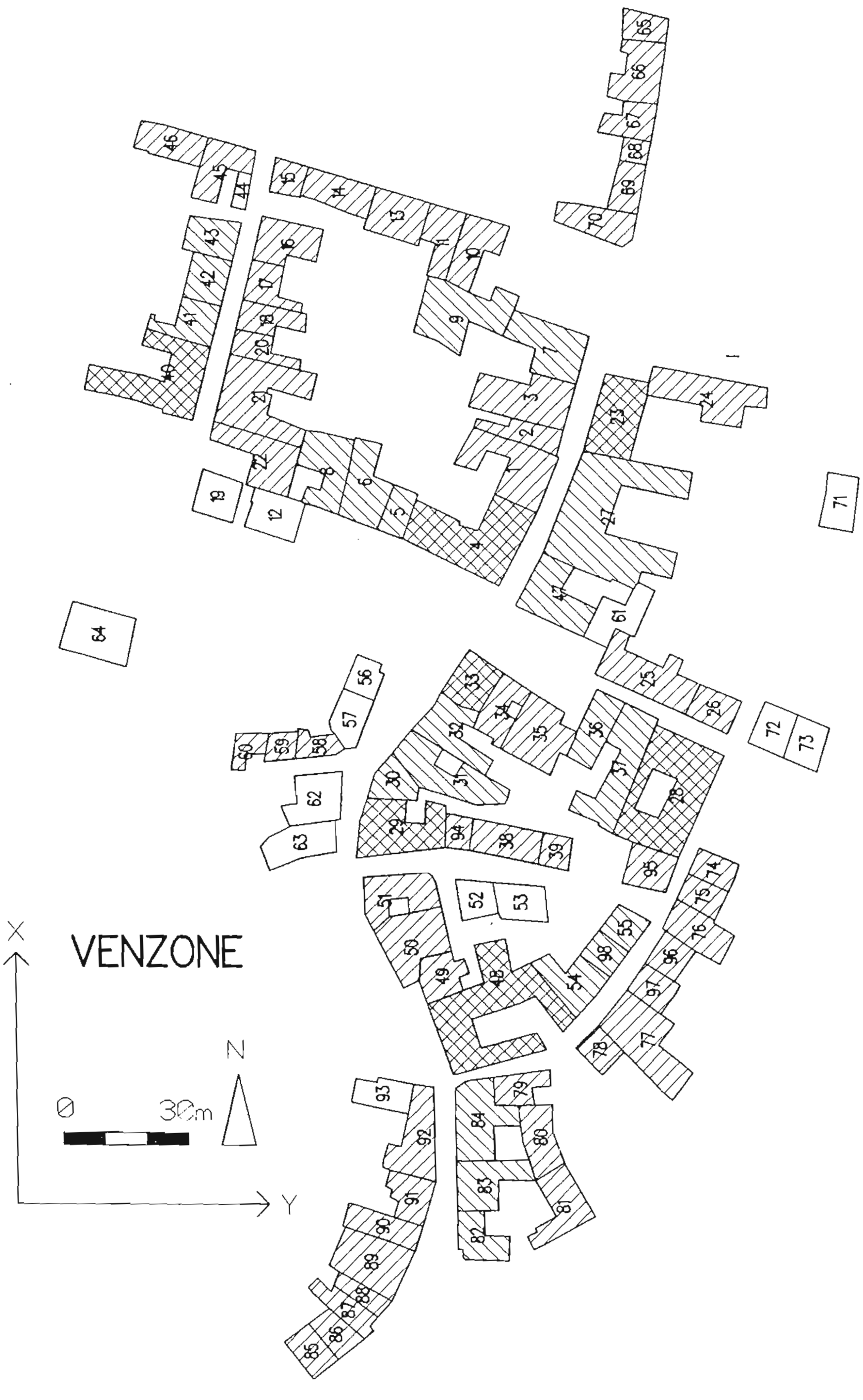


Fig. 9 - All analyzed buildings of Venzone are detected by the sheet number. The sketched polygons indicate the line of continuos buildings matched on the map. The crossing sketched polygons mean the overlapping of the line with different orientation.

Fig. 10 - Table of the results about the line of continuos buildings, positions and vulnerability. The lines of continuos buildings are grouped with a contour box. The dashed box indicates the buildings not belonging to any line (see Fig. 4 for fields' description).

| SCHEDA | USER-ID | AGGR | SCH_X | SCH_Y | POSIZ_X | POSIZ_Y | VUL_Int_X | VUL_Int_Y | VUL_Eff_X | VUL_Eff_Y |
|---|---|---|---|---|---|---|---|---|---|---|
| 85 | 1 | 18 | 1 | 0 | E | N | 41.83 | 49.67 | 46.85 | 55.63 |
| 86 | 2 | 18 | 1 | 0 | I | N | 44.44 | 28.76 | 29.77 | 28.76 |
| 87 | 3 | 18 | 1 | 0 | I | N | 47.06 | 39.22 | 31.53 | 39.22 |
| 88 | 4 | 18 | 1 | 0 | I | N | 46.73 | 38.89 | 31.31 | 38.89 |
| 89 | 5 | 18 | 1 | 0 | I | N | 48.37 | 40.52 | 32.41 | 40.52 |
| 90 | 6 | 18 | 1 | 0 | I | N | 46.73 | 31.05 | 31.31 | 31.05 |
| 91 | 7 | 18 | 1 | 0 | I | N | 51.96 | 44.12 | 39.49 | 48.09 |
| 92 | 8 | 18 | 1 | 0 | E | Af | 38.56 | 38.56 | 46.66 | 23.52 |
| 93 | 9 | 18 | 0 | 0 | N | Af | 31.37 | 15.69 | 31.37 | 15.69 |
| 81 | 10 | 15 | 1 | 0 | E | N | 50.65 | 50.65 | 56.73 | 56.73 |
| 80 | 11 | 15 | 1 | 0 | I | N | 47.06 | 47.06 | 31.53 | 47.06 |
| 79 | 12 | 15 | 1 | 0 | E | Af | 37.58 | 37.58 | 42.09 | 19.54 |
| 84 | 13 | 15 | 2 | 0 | E | Af | 45.75 | 45.75 | 51.24 | 23.79 |
| 83 | 14 | 15 | 2 | 0 | I | N | 47.39 | 39.54 | 31.75 | 39.54 |
| 82 | 15 | 15 | 2 | 0 | E | N | 50.00 | 50.00 | 56.00 | 56.00 |
| 78 | 16 | 14 | 1 | 0 | E | N | 42.16 | 34.31 | 47.22 | 38.43 |
| 77 | 17 | 14 | 1 | 0 | I | N | 52.29 | 44.44 | 35.03 | 44.44 |
| 97 | 18 | 14 | 1 | 0 | I | N | 40.52 | 32.68 | 27.15 | 32.68 |
| 96 | 19 | 14 | 1 | 0 | I | N | 40.85 | 25.16 | 27.37 | 25.16 |
| 76 | 20 | 14 | 1 | 0 | I | N | 41.83 | 33.99 | 31.79 | 33.99 |
| 75 | 21 | 14 | 1 | 0 | I | N | 44.77 | 36.93 | 34.03 | 36.93 |
| 74 | 22 | 14 | 1 | 0 | E | N | 52.61 | 44.77 | 58.92 | 50.14 |
| 53 | 23 | 5 | 0 | 0 | N | Af | 51.63 | 51.63 | 51.63 | 51.63 |
| 52 | 24 | 5 | 0 | 0 | N | Af | 38.56 | 46.41 | 38.56 | 46.41 |
| 51 | 25 | 5 | 1 | 0 | E | N | 49.67 | 41.83 | 55.63 | 46.85 |
| 50 | 26 | 5 | 1 | 0 | I | N | 58.82 | 58.82 | 39.41 | 58.82 |
| 49 | 27 | 5 | 1 | 0 | I | N | 49.67 | 49.67 | 33.28 | 49.67 |
| 48 | 28 | 5 | 1 | 2 | Aa | N | 62.75 | 54.90 | 77.81 | 54.90 |
| 54 | 29 | 5 | 3 | 0 | E | N | 39.54 | 39.54 | 44.28 | 44.28 |
| 98 | 30 | 5 | 3 | 0 | I | N | 41.83 | 26.14 | 28.03 | 26.14 |
| 55 | 31 | 5 | 3 | 0 | E | N | 44.44 | 36.60 | 49.77 | 40.99 |
| 95 | 32 | 4 | 1 | 0 | E | N | 33.33 | 33.33 | 37.33 | 37.33 |
| 28 | 33 | 4 | 1 | 2 | N | Aa | 40.52 | 40.52 | 40.52 | 50.24 |
| 37 | 34 | 4 | 0 | 2 | N | I | 33.66 | 41.50 | 33.66 | 27.81 |
| 36 | 35 | 4 | 0 | 2 | N | Ap | 25.82 | 25.82 | 25.82 | 26.59 |
| 35 | 36 | 4 | 0 | 3 | N | Ap | 47.06 | 47.06 | 47.06 | 48.47 |
| 34 | 37 | 4 | 0 | 3 | N | I | 42.81 | 50.65 | 46.66 | 43.05 |
| 33 | 38 | 4 | 4 | 3 | Aa | Aa | 42.16 | 34.31 | 59.87 | 48.72 |
| 32 | 39 | 4 | 4 | 0 | I | N | 56.21 | 48.37 | 42.72 | 48.37 |
| 31 | 40 | 4 | 4 | 0 | I | N | 58.50 | 50.65 | 44.46 | 50.65 |
| 30 | 41 | 4 | 4 | 0 | I | N | 37.58 | 29.74 | 28.56 | 29.74 |
| 29 | 42 | 4 | 4 | 5 | Aa | Aa | 53.27 | 53.27 | 66.05 | 66.05 |
| 94 | 43 | 4 | 0 | 5 | N | I | 28.10 | 43.79 | 28.10 | 29.34 |
| 38 | 44 | 4 | 0 | 5 | N | I | 40.52 | 40.52 | 40.52 | 27.15 |
| 39 | 45 | 4 | 0 | 5 | N | E | 39.87 | 39.87 | 44.65 | 44.65 |
| 63 | 46 | 6 | 0 | 0 | Af | N | 50.00 | 42.16 | 50.00 | 42.16 |
| 62 | 47 | 6 | 0 | 0 | Af | N | 54.58 | 46.73 | 54.58 | 46.73 |

| SCHEDA | USER-ID | AGGR | SCH_X | SCH_Y | POSIZ_X | POSIZ_Y | VUL_Int_X | VUL_Int_Y | VUL_Eff_X | VUL_Eff_Y |
|---|---|---|---|---|---|---|---|---|---|---|
| **60** | 48 | 1 | 0 | 1 | N | E | 47.06 | 47.06 | **52.71** | **52.71** |
| **59** | 49 | 1 | 0 | 1 | N | I | 38.24 | 46.08 | **38.24** | **35.02** |
| **58** | 50 | 1 | 0 | 1 | N | E | 49.67 | 49.67 | **55.63** | **55.63** |
| **57** | 51 | 1 | 0 | 0 | Af | N | 41.83 | 49.67 | **41.83** | **49.67** |
| **56** | 52 | 1 | 0 | 0 | Af | N | 50.98 | 43.14 | **50.98** | **43.14** |
| **64** | 53 | 8 | 0 | 0 | Is | Is | 44.77 | 29.08 | **44.77** | **29.08** |
| **73** | 54 | 13 | 0 | 0 | N | Af | 36.60 | 44.44 | **36.60** | **44.44** |
| **72** | 55 | 13 | 0 | 0 | N | Af | 26.47 | 26.47 | **26.47** | **26.47** |
| **71** | 56 | 13 | 0 | 0 | Is | Is | 36.27 | 44.12 | **36.27** | **44.12** |
| **24** | 57 | 3 | 0 | 1 | N | N | 59.80 | 51.96 | **59.80** | **51.96** |
| **23** | 58 | 3 | 2 | 1 | Aa | Aa | 49.35 | 41.50 | **61.19** | **51.46** |
| **27** | 59 | 3 | 2 | 0 | I | N | 63.07 | 55.23 | **42.26** | **55.23** |
| **47** | 60 | 3 | 2 | 0 | E | Af | 43.14 | 50.98 | **48.32** | **26.51** |
| **61** | 61 | 3 | 0 | 0 | N | C | 37.91 | 45.75 | **37.91** | **45.75** |
| **25** | 62 | 3 | 0 | 3 | N | Ap | 31.16 | 39.00 | **31.16** | **40.17** |
| **26** | 63 | 3 | 0 | 3 | N | E | 41.50 | 49.35 | **46.48** | **55.27** |
| **16** | 64 | 2 | 1 | 0 | E | N | 45.42 | 53.27 | **50.87** | **59.66** |
| **17** | 65 | 2 | 1 | 0 | I | N | 37.91 | 30.07 | **28.81** | **30.07** |
| **18** | 66 | 2 | 1 | 0 | I | N | 53.59 | 37.91 | **40.73** | **37.91** |
| **20** | 67 | 2 | 1 | 0 | I | N | 47.06 | 31.37 | **31.53** | **31.37** |
| **21** | 68 | 2 | 1 | 0 | I | N | 34.31 | 26.47 | **22.99** | **26.47** |
| **22** | 69 | 2 | 1 | 0 | E | N | 53.92 | 46.08 | **60.39** | **51.61** |
| **12** | 70 | 2 | 0 | 0 | N | C | 27.45 | 19.61 | **27.45** | **19.61** |
| **8** | 71 | 2 | 0 | 2 | N | Ap | 49.02 | 56.86 | **49.02** | **58.57** |
| **6** | 72 | 2 | 0 | 2 | N | I | 46.73 | 54.58 | **46.73** | **36.57** |
| **5** | 73 | 2 | 0 | 2 | N | I | 44.12 | 51.96 | **48.09** | **39.49** |
| **4** | 74 | 2 | 3 | 2 | Aa | Aa | 44.44 | 36.60 | **63.10** | **51.97** |
| **1** | 75 | 2 | 3 | 0 | I | N | 53.59 | 45.75 | **40.73** | **49.87** |
| **2** | 76 | 2 | 3 | 0 | I | N | 48.04 | 32.35 | **32.19** | **32.35** |
| **3** | 77 | 2 | 3 | 0 | Ae | N | 60.13 | 52.29 | **65.54** | **52.29** |
| **7** | 78 | 2 | 0 | 4 | C | E | 58.82 | 50.98 | **65.88** | **57.10** |
| **9** | 79 | 2 | 0 | 4 | N | Ap | 59.80 | 51.96 | **59.80** | **53.52** |
| **10** | 80 | 2 | 0 | 5 | N | Ap | 19.61 | 27.45 | **21.37** | **33.21** |
| **11** | 81 | 2 | 0 | 5 | N | I | 41.83 | 41.83 | **45.59** | **35.56** |
| **13** | 82 | 2 | 0 | 5 | N | I | 39.87 | 39.87 | **39.87** | **26.71** |
| **14** | 83 | 2 | 0 | 5 | N | I | 34.97 | 34.97 | **34.97** | **23.43** |
| **15** | 84 | 2 | 0 | 5 | N | E | 27.12 | 27.12 | **30.37** | **30.37** |
| **19** | 85 | 2 | 0 | 0 | Is | Is | 40.20 | 48.04 | **40.20** | **48.04** |
| **40** | 86 | 9 | 2 | 1 | Aa | N | 46.08 | 38.24 | **57.14** | **38.24** |
| **41** | 87 | 9 | 2 | 0 | I | N | 46.73 | 38.89 | **31.31** | **38.89** |
| **42** | 88 | 9 | 2 | 0 | I | N | 39.54 | 31.70 | **30.05** | **34.55** |
| **43** | 89 | 9 | 2 | 0 | E | N | 6.54 | 6.54 | **7.91** | **7.91** |
| **44** | 90 | 9 | 0 | 0 | C | N | 7.52 | 7.52 | **7.52** | **7.52** |
| **45** | 91 | 9 | 0 | 3 | C | E | 48.04 | 55.88 | **58.13** | **67.61** |
| **46** | 92 | 9 | 0 | 3 | N | E | 48.37 | 56.21 | **58.53** | **68.01** |
| **70** | 93 | 10 | 1 | 0 | E | N | 33.99 | 33.99 | **41.13** | **41.13** |
| **69** | 94 | 10 | 1 | 0 | I | N | 49.67 | 41.83 | **42.22** | **45.59** |
| **68** | 95 | 10 | 1 | 0 | I | N | 39.54 | 31.70 | **30.05** | **31.70** |
| **67** | 96 | 10 | 1 | 0 | I | N | 49.67 | 33.99 | **37.75** | **33.99** |
| **66** | 97 | 10 | 1 | 0 | I | N | 52.29 | 52.29 | **39.74** | **52.29** |
| **65** | 98 | 10 | 1 | 0 | E | N | 61.76 | 53.92 | **69.17** | **60.39** |

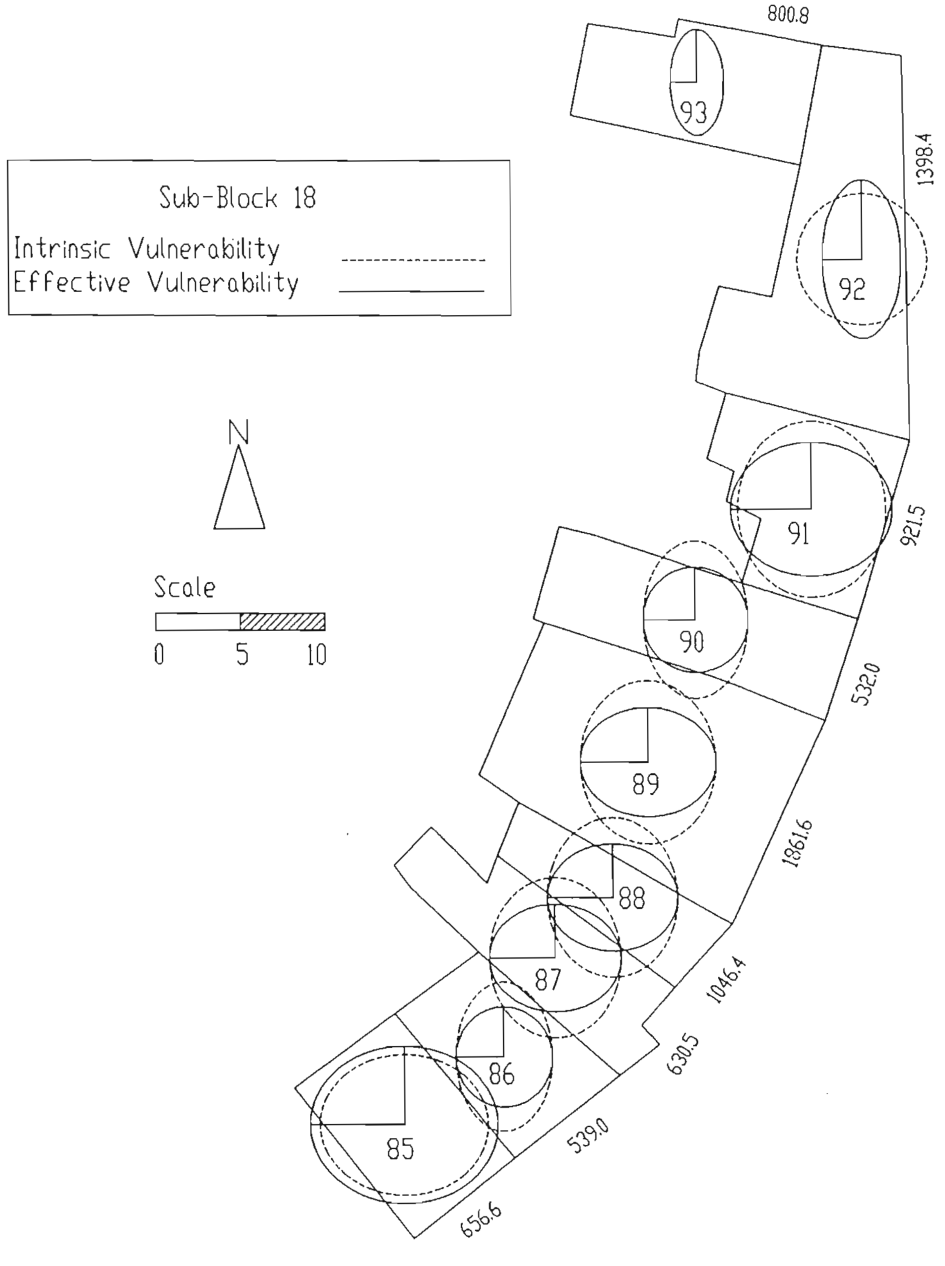


Fig. 11 - Vulnerability ellipse for all buildings of sub-block 18.

In figure 11, the entire sub-block n° 18 is represented; on every building, the vulnerability ellipse can be found. The dimensions of the axes, located on the centroid of every building, are proportional to the vulnerability in two directions. Analyzing the shape difference of every pair of ellipse, one has an immediate indication of the spatial variation of the vulnerability. The buildings in an internal position of the line of continuous buildings (n° 86, 87, 88, 89, 90 and 91) show a sensible reduction of the vulnerability index in *X* direction. Building n° 85 on the extreme part of a line of continuous buildings shows a light increment in both directions, whereas building n° 92 has a limited effect of extremity only in *X* direction due to the influence of building n° 93 in nearby position. It has to be reminded that the vulnerability of building n° 93 does not vary as it does not belong to the line of continuous building. The values at side of every building represent the volume, in $m^3$, calculated using the GNDT sheet data. This value will be used for the vulnerability calculation of complex sub-block systems.

In figure 12, on the left side, a single polygon points out the line of continuous buildings identified on sub-block n° 18, thus considered as a single structural element whose vulnerability is represented by only one global ellipse. The values of the semi-axes are obtained by the calculation of the medium values of the vulnerability indices of every building weighted according to the corresponding volumes. Building n° 93, in a nearby position to the line of continuous buildings maintains the proper value unchanged. On the right side, analogously, the effective vulnerability of the whole sub-block n° 18 is shown, considered as a single structural element. In the chosen example, the difference can only be estimate by numbers, but it can result much more evident if more complex sub-blocks are considered.

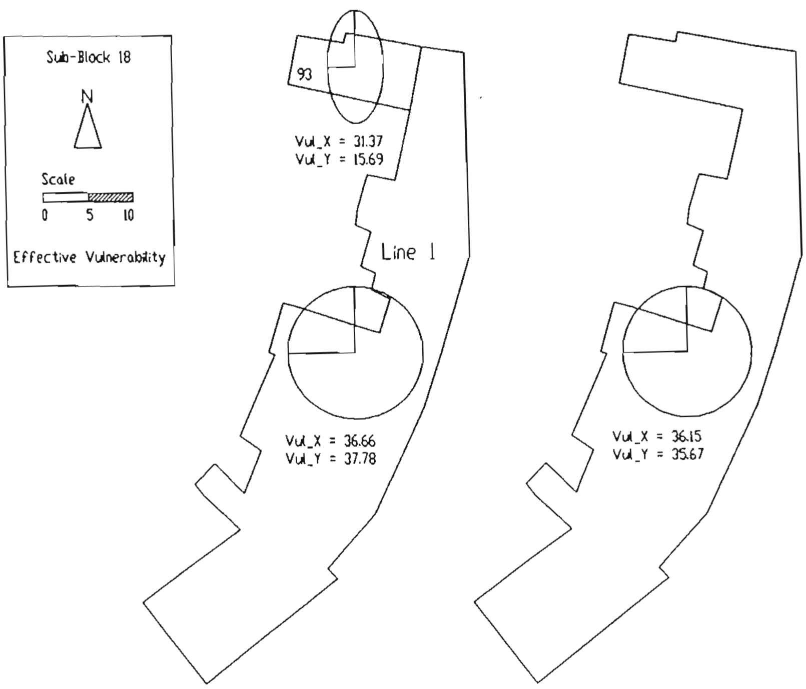


Fig. 12 - Effective vulnerability ellipse for sub-block 18.

## 7 - CONCLUSIONS

The instruments adopted to realize the expert system have shown some limits. As already pointed out, the integration of the two environments Arc/Info and Nexpert has only taken place at the level of data sharing. The principal reasons for this are the well-known limits given by the operating system MS-Dos and by the limited capability of the used release of PC Arc/Info, that are not yet able to operate in environments such as Windows 3.1.

Future developments of the prototype realized will depend on future releases of the software packages or on the migrations to multitasking operating systems. The availability of the adopted instruments on UNIX environment, the full porting of the coverages and the knowledge base will be a exciting experience (Maidment and Djokic, 1991) [9] in which the integration of the adopted instruments will enable a connection at the level of commands to both software environments.

A upper bound limit is the vectorial approach of the PC Arc/Info. Unfortunately, the structure of the system does not enable the final user to have a complete availability of all data regarding the coordinates of point and arc features. This fact has bound the prototype analyses for an conceptual description of the building form. The availability of the whole set of data could permit a more efficient and profitable analysis for the vulnerability assessment of the structures.

The adopted procedure does not only permit the assessment of the ellipse of effective vulnerability of the single buildings but allows to assess the vulnerability of the sub-blocks, the blocks and even complete urban structures. A damageability index of the whole structural system can also be represented as the mean of vulnerability rays of the ellipses of the single buildings in the various directions weighed with the volumes of the buildings themselves. If two principal directions are considered, an effective vulnerability ellipse can be defined for the complete structural system. This operation obviously can only be effected as long as the extension or the geomorphological characteristics of the interested area do not reject the validity of the hypothesis to assume that the shaking direction is the same for all buildings. The dimensions of the ellipse can be used, in a first approximation, as a measure relating to the complex vulnerability of the various structural systems in consideration.

The prototype in this work allows to establish automatically, by means of clearly codified rules, the vulnerability assessment of buildings in a structural context. At the same time, it is an instrument that allows to make forecasts on the expected damage as a consequence of an hypothesized seismic event; it is therefore a useful method for the conduction of risk analyses.

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