A case study for seismic vulnerability assessment using GIS connected to Expert System

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ABSTRACT

The definition of seismic risk in urban areas raises the problem of the seismic vulnerability assessment of construction properties with the estimation of the tendency to damage of a number of buildings. Very often one is confronted by 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 acquisition of information on existing buildings, which must furnish a sufficiently reliable assessment of the seismic damageability.

With relation to other work based on this argument, the proposed system automatically assesses a large quantity of geocoded data of geometry and of 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 National Project for Seismic Prevention of the National Council for Research.

By means of Arc/Info the morphologic features and adjoining relationship of the buildings can be derived for their topological description. All this information is stored in tabular form and are transferred to the expert system in objects data structure. The model uses an expert system to codify the knowledge basis of the effective vulnerability assessment rules for regular and irregular building blocks, and to apply it automatically on the basis of the results obtained by processes of spatial analyses calculated by Arc/Info GIS.

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1. INTRODUCTION

The preservation of the buildings state in seismic areas points out some activities directed at the global definition of the seismic risk and at possible damage reduction. As for buildings of both historical and modern origin, as in the case of the italian situation, we get heterogeneous structural characteristics. The studies on the buildings vulnerability are meant to define those characteristics estimating the tendency to damage in relation to a given seismic event. This leads to the search for procedures , so as to improve collection and quickly estimate the data necessary to assess the vulnerability.

In case there are numerous buildings to analyse, it is also necessary to use a rapid procedure, most reliable as possible, systematic and yielded through modern systems.

Among the procedures estimating the vulnerability the best are those based on the buildings typological classification and on posterior damage evaluation. Other methods based on numerical analysis of the structural behaviour are however seldom adopted in case of wide areas and large number of buildings. This method suffers also a lack of experimental data on different building typologies.

Further methods, called *hybrid,* add to the previous ones also a series of structural parameters identifying the seismic behaviour of a building; besides each parameter concurs in weighted form to the estimation of the vulnerability index appointed to each building.

Previous works proposed different procedures for the vulnerability assessment (Benedetti D. e Petrini V., 1984) [2] e (Angeletti C. e Gavarini C., 1984) [1]. These procedures have been adopted by GNDT (National Project for Seismic Prevention) using sheets for the collection of the typological data of the studied buildings.

Information stored on GNDT sheets therefore became basis for data, on which afterwards methods for the vulnerability estimation evolved. On the same sheets some seismic vulnerability estimations have been achieved through expert systems for the data uncertainty treatment.

The data stored on the GNDT sheet and the analyses that only refer to the recorded information are, however, limited to single buildings, ideally understood as isolated. Carefully studying the damage caused by past earthquakes we note differences in behaviour between isolated buildings and those placed in a overall structural context, as for instance for adjoining buildings.

An alternative approach and maybe complementary attempt, presented in this work, is to assess the vulnerability of buildings in an overall structural context using Geographic Information Systems for mapping the urban system, integrated with the surveys transferred on GNDT sheets.

In particular the proposed system automatically assesses a large quantity of geocoded data either in geometry and in the structure through the Geographic Information System PC Arc/Info connected with the expert system shell Nexpert Object, starting from the methods used by 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 on the context (Grimaz, 1992-93) [6] [9].

2. THE STUDY SITE AND THE DATA SOURCES

Fig. 1 - Aerial survey of the centre of the town of Venzone

The study area is the centre of Venzone town (**Fig. 1**) located to the north of the city of Udine (Friuli, Italy) at the head of the Tagliamento valley, with the Carniche foothills behind. The site began its economic growth around the year 1200 with the growth of trade with other european countries. The town centre is surrounded by city walls built in masonry buildings of about two-four floors. From the seismic catalogue list we can identify, starting from the year 1000, seven seismic events with an intensity greater then VII. The recent events of May, 1976, and again in September of the same year with an intensity of IX on the Mercalli scale, damaged the quasi-whole of buildings and destroyed some of them. This allows to fill in the vulnerability forms as the state preceding the first event of May, and in the middle of two events. At the same time this situation permit to check all the damage after each of the two seismic events. The documents investigated were available in the municipality archives of images, made by professional reporters and unprofessional. The metric data of buildings has been evaluated mostly from cadastral documents and from graphical reconstruction also with the aid of professionals and students. A total of 98 buildings with sufficient data were investigated in the study area. Those buildings that had been subject to partial or complete collapse were excluded from the study. The GNDT sheets are in paper form and are formed by eight sections and two more sheets describing specifically the buildings in masonry and in concrete with a total of 264 fields.

3. THE VULNERABILITY ASSESSMENT

The vulnerability assessment developed in the GNDT project is factors analysis-based on the typologic characteristics of the building's components. These, as explained in the previous section, are arranged in sheet forms and allow the vulnerability estimation in relation to some parameters that are representative for the predisposition of masonry buildings to suffer damages caused by seismic events. Some of them refer to the behaviour of the structure elements, others to the behaviour of the overall body. The set of parameters that are up to now evaluated are eleven:

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

For each parameter is assigned a score in relation to four classes that define the state [2], and, more, each parameter contribute with a weight that has been experimentally tested. The intrinsic vulnerability of each building is finally defined with a unique index that takes into account the sum of all parameters with relative weight.

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

where p_i corresponds to the score of the indexed parameter and w_i to the weight of the same parameter.

The obtained index is representative of the intrinsic vulnerability, that is the tendency of the building to suffer damages, understood as independent of the structural context formed by the adjacent buildings and without considering the direction of greatest damageability caused by seismic waves.

The damage that a building suffers is generally dependent on the shaking direction, in a first approximation, the complete vulnerability development can be represented by an ellipse (Grimaz S., 1992) [6] having axes proportional to the vulnerability indices always assessed with the relation (1), for both principal directions X and Y.

We define with this method an ellipse of intrinsic vulnerability **U** which mean the vulnerability in the two main shaking directions where the axis of the ellipse in the **k** direction is computed as follows:

$$U_k = \Sigma_i \, p_{ik} \; w_i \qquad K = x,y \qquad (2)$$

In order to take into account the influence of the structural context, considered as a set of adjacent buildings, one has to individuate a set of factors that can modify the building damageability, changing from the intrinsic condition, that is relative of the typological characteristics of the building itself, to the effective one that is more sensitive to the adjacent structures in which the building under evaluation is inserted.

The effective vulnerability **V** is therefore obtained deforming the intrinsic ellipse by the presence of the context factors **f**.

$$V = \beta \times U \qquad (3)$$

where β is the function of deformation and is defined as follows (Grimaz, 1993) [9]:

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

In the case of an isolated building, where no context factor is activated, β assumes the value 1, and the effective vulnerability ellipse corresponds with the intrinsic one. In the 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
$\mathbf{f}_{cs}$ overall effects of structural context
$\mathbf{f}_{ds}$ effects due to a structural inhomogeneity

so that the relation (4) assumes the following

$$\beta(\beta_x,\beta_y) = (1+ \mathbf{f}_{cl} + \mathbf{f}_{cs} + \mathbf{f}_{ds}) \quad (5)$$

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. For each position a percentage 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 of the material or the presence of structural discontinuity. This factor also makes part of the information furnished by GNDT sheets.

From these factors take relevant phase the position assignement as for is evident that for the solution of relation (3) we need that each building "knows" its position and the position of the adjacents. The solution appear in some cases very exacting since the sheets information must be integrated with a urban plan. Connecting the alphanumerical information with the graphic one, it is thus possible to reconstruct geometrical properties on which the positions can then be individuated.

4. DEFINITION OF BUILDINGS AND POSITIONS

For a better comprehension of the meaning of structural context and of buildings position, we thought it right to insert in succession a set of definitions which, referred to Venzone old town, consider the whole range of cases (**Fig. 2**). A great effort has been made to join in corresponding assessing of the positions defined "a priori" in theoretic considerations with those really found in the Venzone study. It is possible we didn't succeed to define all general cases nor to generalize definitively the positions, in any case the proposed method will be experimented on a new town settled in a different geographic context.

Fig. 2 - Buildings' map of the Venzone old town. The circled numbers indicate the existing regular sub-blocks. The bold drawn bildings show where the effective vulnerability has been calculated.

General:

length: dimension referred to the direction of the street;

width: dimension referred to the orthogonal direction of the street.

Set of buildings (**Fig. 3**):

block: a set of buildings in contact

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

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

contiguous buildings if they develop a total length of less than 2.5 of their height, or if there are no interruptions

adjacent buildings in all other cases;

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

break due to change in axis translation: when the distance between the median axes of two series of contiguous and aligned buildings is equal or greater than the mean width of the buildings.

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

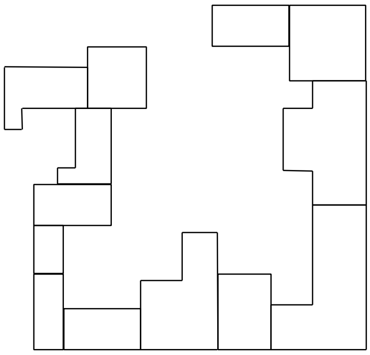
break due to changes in structural properties: presence of separation joints having effects for seismic purposes; lowering of the roof line above 2/3 (e.g. changing from three floors to one); presence of main entrance of a height equal to at least half of the building height; presence of a building with 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:

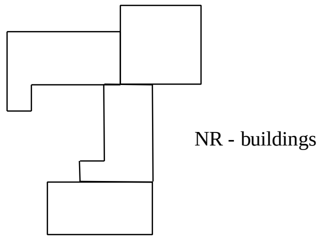
irregular sub-blocks: if no predominant alignment can be individuated

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

BLOCK

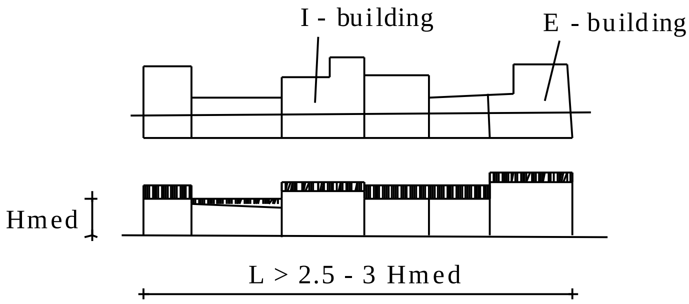


IRREGULAR SUB-BLOCKS

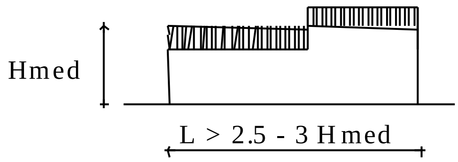


REGULAR SUB-BLOCKS

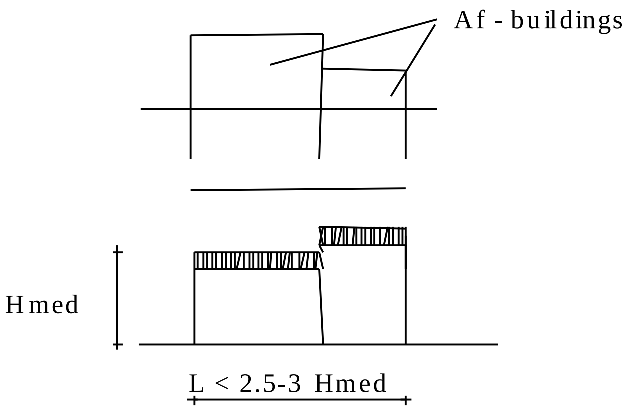
BUILDING ARRAY



LONG BUILDING



CONTIGUOUS BUILDINGS



ADJACENT BUILDINGS

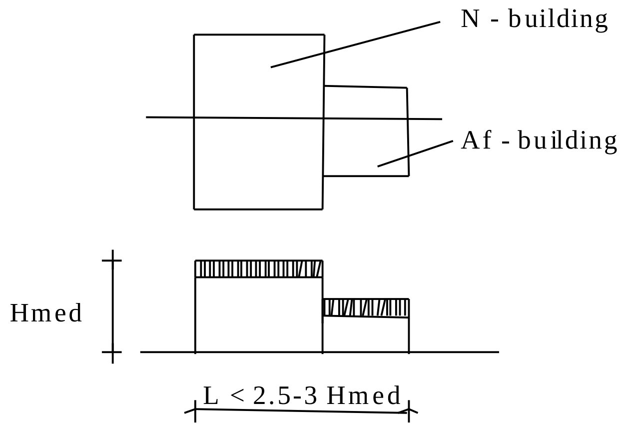


Fig. 3 - Example of buildings configuration and position assignment.

5. ASSIGNEMENT OF THE POSITIONS

To satisfy the relation (3) and consequently the relation (5) it is necessary to identify or estimate for each building its own position according to *adjacent buildings*. This process develops by an analyses in more cascade levels, that it is possible to define by successive approximations. The first level acts for the investigation of the whole environment (in this case Venzone town) individuating the structural blocks and lonely buildings; the second one 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* (**Fig. 4**) or *joint* between these. A third that defines the position assumed by the building inside the *sub-blocks*.

For each level "candidates at certain positions" are defined and then "elected" or not in the level of subordinated analysis. The procedure of assignment of the position develops in different stages connected among each others that render the objective assignment 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 position of the single buildings. The automatic process we have got ready 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.

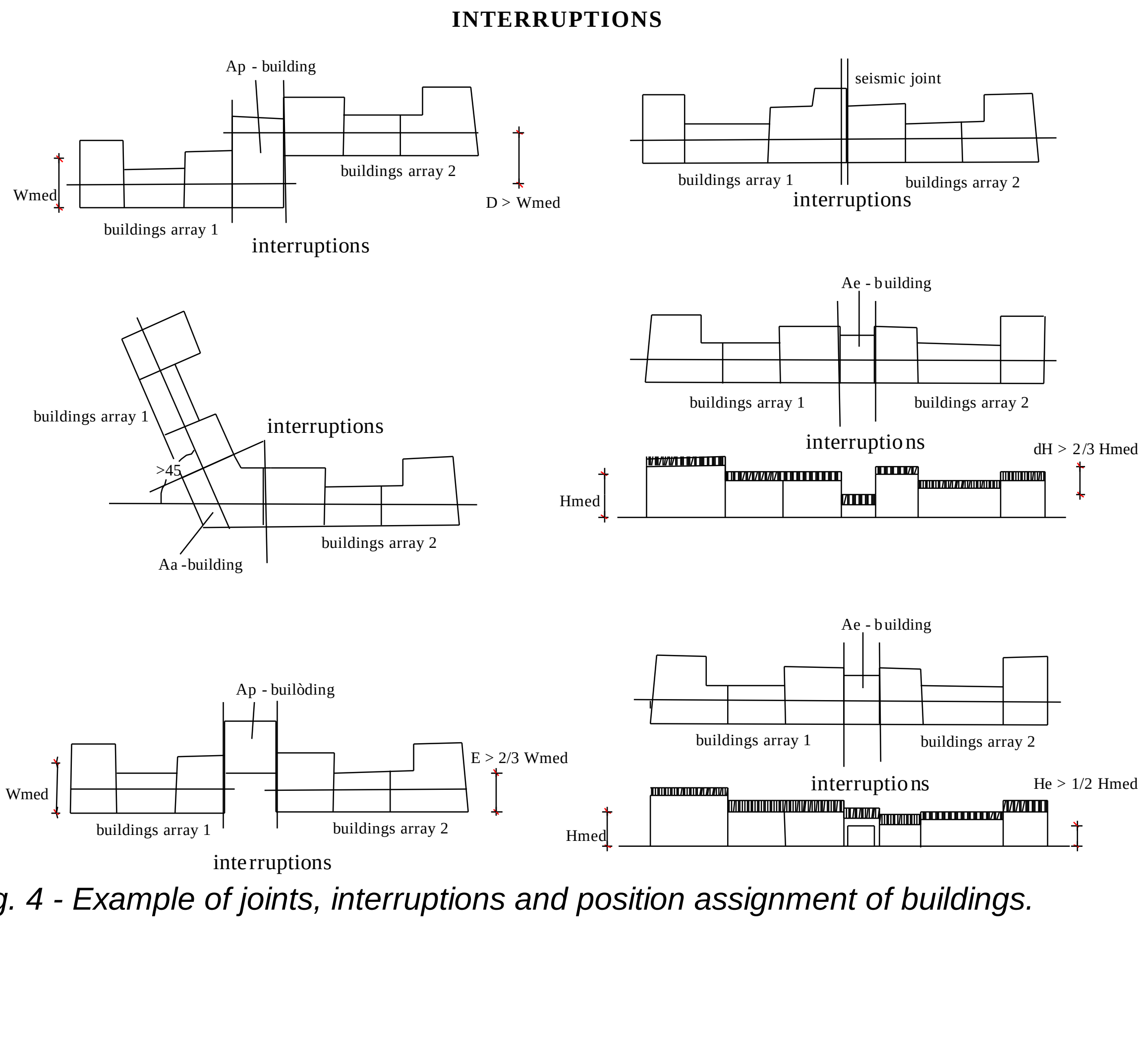


Fig. 4 - Example of joints, interruptions and position assignment of buildings.

5.1 DEFINITION OF GENERAL RULES

For each of the two principal directions of the building that are congruent with the inspected X and Y direction (used for the compilation of the intrinsic vulnerability evaluation in the GNDT sheets), it is led the assignment of the position. On the basis of the member of a building the following cases appears, that is to say *regular* and *irregular sub-blocks*.

Regular sub-blocks

CONTIGUOUS BUILDINGS

Let *N-building* **N** (neutral) for the bigger building
Let *Af-building* **Af** (articulated) for the smaller building

ADJACENT BUILDINGS

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

BUIDINGS ARRAY

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 buildings array
with axis translation;
Ae *A-building in elevation*
large main entrance, heavy lowering;
Aa *A-building in angle*
building in angle position

Let *I-building* **I** (internal) if the building is not in an *A-building* and is in contact on both sides of the building in the direction of the buildings array to which it belongs.

Let *E-building* **E** (external) if the building in not in an *A-building* and the building only has one contact in the direction of the buildings array 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 buildings array.

Irregular sub-blocks

In this case the *position* is defined *irregular* and the influence is estimated each time by a detailed analysis of the structural situation of the context.

A percentual score $\mathbf{f}_{cl}$ is associated to the indices of irregularity shape, whereas there is a percentual score $\mathbf{f}_{cs}$ for every position.

By the evaluation of alphanumeric data in the GNDT sheets it is possible to activate those factors that give rise to structural inhomogeneity, which a further percentage rating $\mathbf{f}_{ds}$ is associated to.

Thus, for both principal directions β is determined by (5) and the effective vulnerability is defined by (3).

6. ARC-INFO and NEXPERT STRATEGY

Arc/Info and nexpert systems are commonly used by many research groups in the GNDT; so integrations and data exchange inside the GNDT are easily performed. 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) [8], whereas Nexpert can be integrated into any program written in C language [4]; 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 links and relations 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.

7. DATA PROCESSING AND THE EXPERT SYSTEM

7.1 PREPROCESSING

The territorial information of the old town of Venzone has been digitized from the photogrammetric survey in scale 1/2000 in Autocad format.

The map with the plan of buildings of the whole municipality has been imported into Arc/Info using the Autocad DXF format. This digitalization, after having been filtered and cleaned from the imprecision's of acquisition, has thus assumed the form of Arc/Info coverage "*Edifici*" (**Fig. 2**) which has produced a double shape of arc and polygon topology; with these instruments Arc/Info associates geocoded information to table information in dBASE III+ format which describe the relation between the arcs (AAT file - Arc Attribute Table) and the polygons coverage (PAT file - Polygon Attribute Table).

The structural-engineering data collected in the previous surveys and recorded on the vulnerability sheets of the 1st e 2nd level 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. The following represents 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

The relation between the map reference and the data base of the GNDT sheets is made with the following additional fields: AGGR = sub-block and SCHEDA = number of GNDT sheet that identify the building (**Fig. 6**). It has been necessary to indicate the street front and the sides of the buildings that are located on the street front, univocally numbered. This operation is important for the automatic recognition of a *buildings array* and the positions of the buildings inside the line. In this step are assigned also the orientations of the street fronts with respect to the cartesian directions of analysis *X* and *Y*, that have clearly been individuated on the whole town. 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. 5**, this information is stored in the attribute fields of the AAT file (fields FRONTE_S and ORIEN).

AAT file structure - VENZONE Coverage

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

Fig. 5 - Format of the AAT tables of Venzone coverage, in the last two items are located the attributes of the street front sides.

7.2 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. 2**). The buildings that do not have this information are eliminated from the coverage in order to obtain a sub-set of 98 buildings to analyze (bold in **Fig. 2**). Furthermore, the following process does not take into account the isolated buildings without information (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 to locate the *buildings array* and the position of the buildings itself, 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 each 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 τ_k value which is the characteristic resistance of masonry, from the 2nd level sheet. In this way the structure of the PAT of Arc/Info allows to gain precious information which is very useful in the analysis of the overall 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.

This information was directly obtained by Arc/Info commands as in case 1 and by means of a written SML procedures in cases 2 and 3.

To identify adjacent polygons (buildings) we used a two steps operation: first of all we reconstructed the PAL (polygon arcs list), using the information stored in the AAT, then for each polygon the list of adjacent polygons was compiled , besides the sides of street front has been found with a semi-manual procedure, aided by an SML routine that allows to select a polygon, which is hilighted by a different colour, and then to select a street front, also lighted by a different colour, after that the Macro asks to introduce the univocal street front number, and its orientation; the length is automatically derived by the AAT.

The information is then saved in appropriate fields that are prepared in the PAT table. In particular, the centroid of every polygon is saved in the fields X_COORD and Y_COORD, in UTM coordinate (case 1). The adjoining buildings are saved in POL_ADD1 to POL_ADD6 fields (case 2), while the information of the arcs (case 3) for both reference directions are saved in the fields FRONTE_SX, FRONTE_SY and LUNG_FSX, LUNG_FSY (**Fig. 6**). Other data, such as the area and the perimeter of every polygon are standard in the Arc/Info table.

PAT file structure - VENZONE Coverage

	AREA PERIMETER POLY# USER-ID	: PAT standard items
	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	: t_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	: buildings array number along X direction
	SCH_Y	: buildings array 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. 6 - 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.

7.3 CONNECTING ARC/INFO AND NEXPERT OBJECT

The connection between the GIS and the expert system developed with the Nexpert Object Shell has been made 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.

Nexpert Object is able to read and write directly the Feature Attribute Table of Arc/Info, and creates for every record of the table a new spatial object inside the data structure of the expert system. In **Fig. 7** it can be seen how each PAT element (i.e. record means building) is converted into an object in the working memory of Nexpert belonging to the *Edifici* class . 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 *buildings array*. 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 PAT for the representation of the results in graphic form.

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

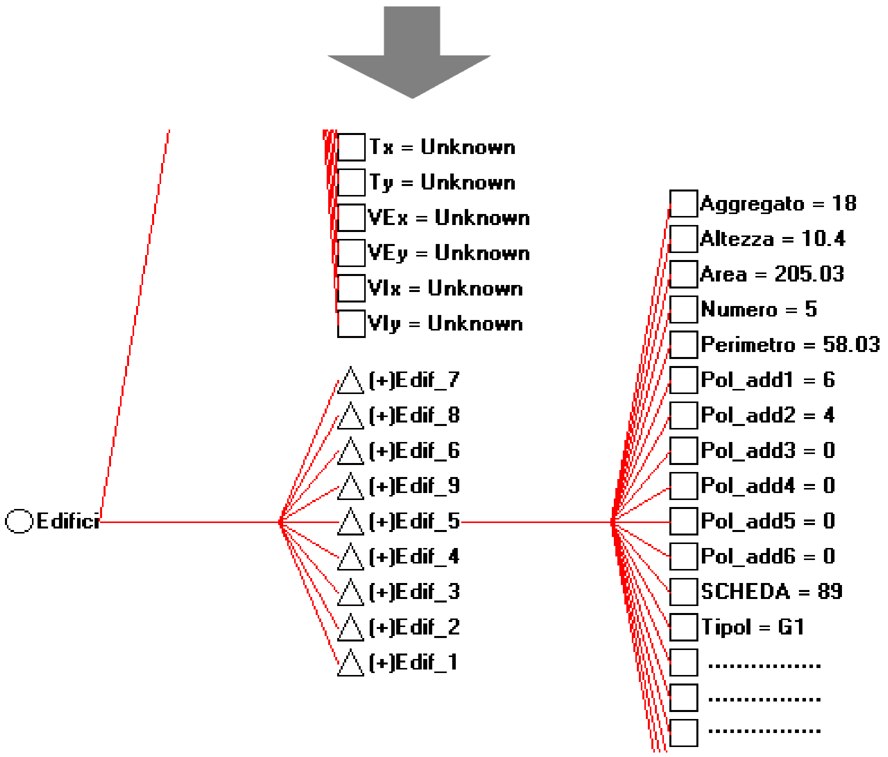


Fig. 7 - Porting data from Arc/Info to Nexpert: record n° 73 (User-Id = 5, Sheet = 89) of the PAT imported into Nexpert becomes the object Edif_5 and inherits the properties of the class Edifici.

7.4 DEVELOPMENT OF RULES FOR A *BUILDINGS ARRAY*

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

The individuation of the *buildings array* is complex and 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 transformed following the relationship and represented by logical links between the objects of the class *Edifici* (**Fig. 8**).

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. 9**).

These groups are a first step of building subdivision into classes of *candidates of a buildings array*, 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 buildings array.* Then the following *A-buildings* are recognized and assigned:

Ae : break due to discontinuity elevation (Δ 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 features of the polygon topology: centroid coordinates, area, perimeter and street fronts. Furthermore, the *long buildings* in the sub-block are detected; this is a 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 buildings array* that have previously been individuated are examined again in function of their dimensions, in order to check whether the necessary conditions are fulfilled for the presence of the *buildings array*.

The buildings belonging to *buildings array* evaluated *true* 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 of this process we have marked the positions of the buildings inside the *buildings array* along both directions of analysis. The positions *I-Building, E-Building* and finally also the *Aa-buildings* are assigned.

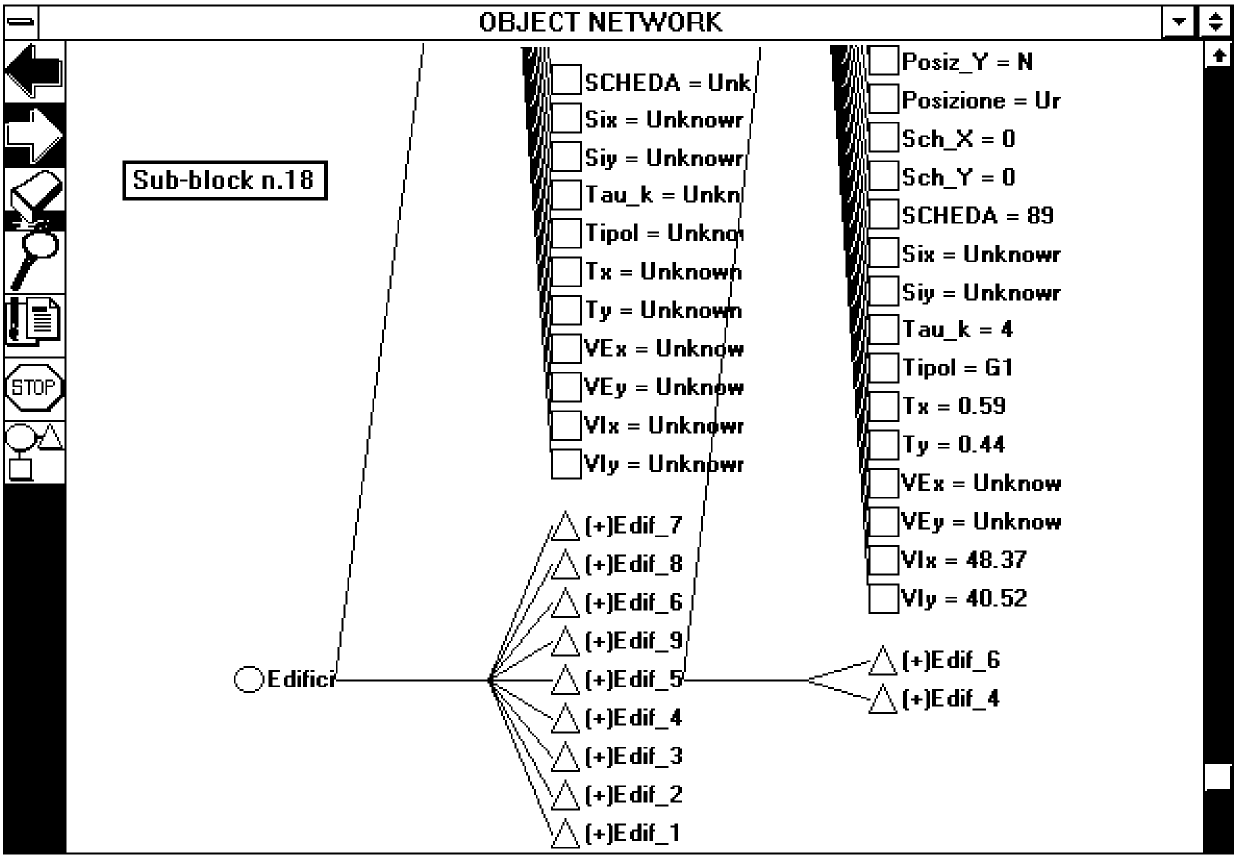


Fig. 8 - Relationships between the objects of the class Edifici in the Environment Nexpert Object. The objects Edif_4 and Edif_6 (sub-block n° 18) result adjacent to the building Edif_5, as indicated by the links.

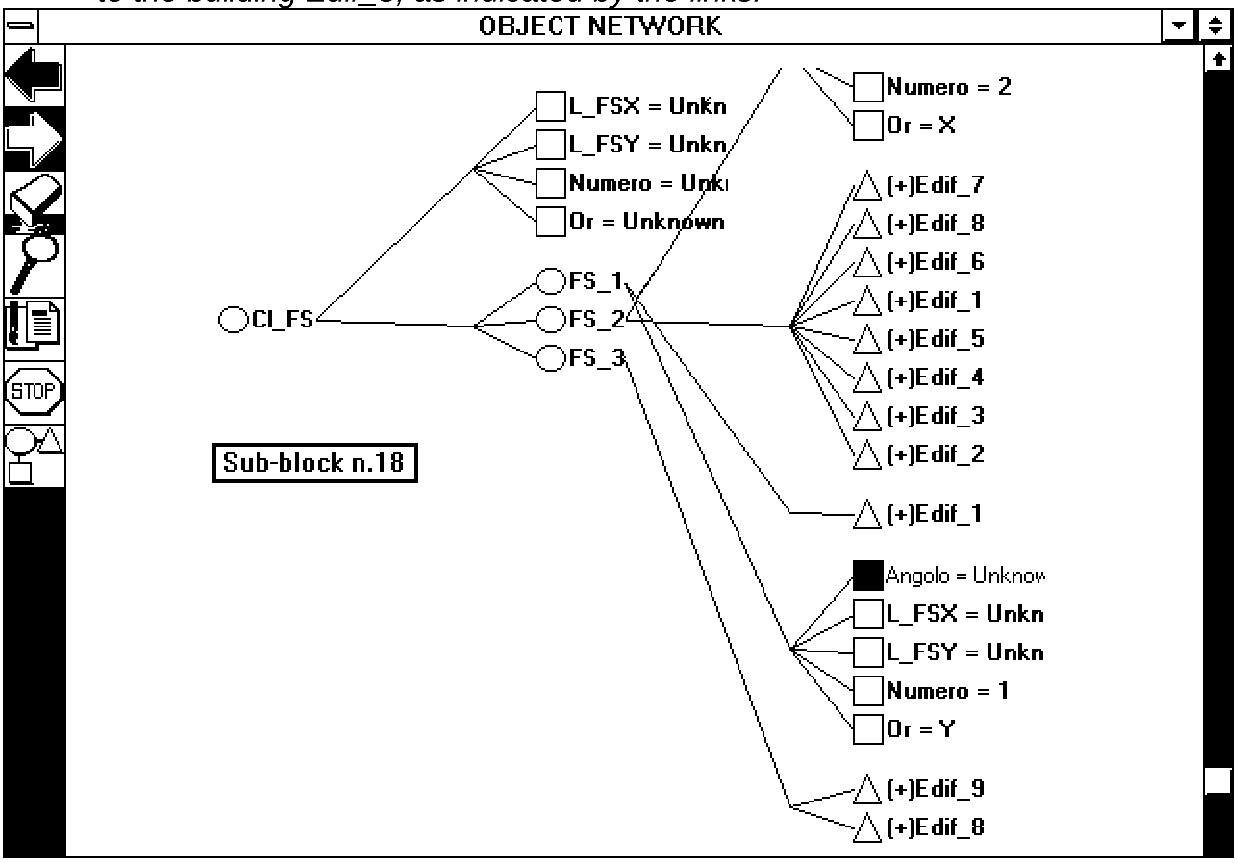


Fig. 9 - Connection between Class and Object for the description of the street fronts. The classes FS_1, FS_2 and FS_3 contain the buildings belonging to three different street fronts individuated on sub-block n° 18.

7.5 DEVELOPMENT RULES FOR EFFECTIVE VULNERABILITY ASSESSMENT

The revision of vulnerability values on the structural context, that is the assessment of the modifications involved in the buildings behaviour by the presence of adjacents, is effected on the basis of a set of rules that evaluate for each buiding belonging to a certain *building array* the activation of the various factors that make the relation (5).

The characteristical factors of the structural context can be represented in three classes as follows:

1 - *Local* context effects.

f_1 : lengthening of the building;
f_2 : irregularity of the building geometry;
f_3 : lowering of the roof line (1 floor < Δ height < 2 floors) of a buildings array.

2 - *Overall* context effects.

The position **E**, **I**, **A_a**, **A_p**, **A_e** and **A_f** as previously defined.

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

D: structural typology consisting of six classes;

τ_k: characteristic resistance, only if the structural typology D is different.

The information relating to the overall effects of the context 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 estabilished by the information in the feature attribute table previously described.

Furthermore the **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 **f_1** and **f_2** are not considered.

All factors of the structural context are associated to weights that have been estimated in a previous work [10], 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 in **Fig. 10**. For every building, the effective vulnerability factors are calculated and shown by a dialogue box in an 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 plot 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**	**-0.3**	**0.24**	**0.03**	**0.09**	**-0.48**	**0.09**

*Fig. 10 - The used weights of the effects **f_j** from the relation (5).*

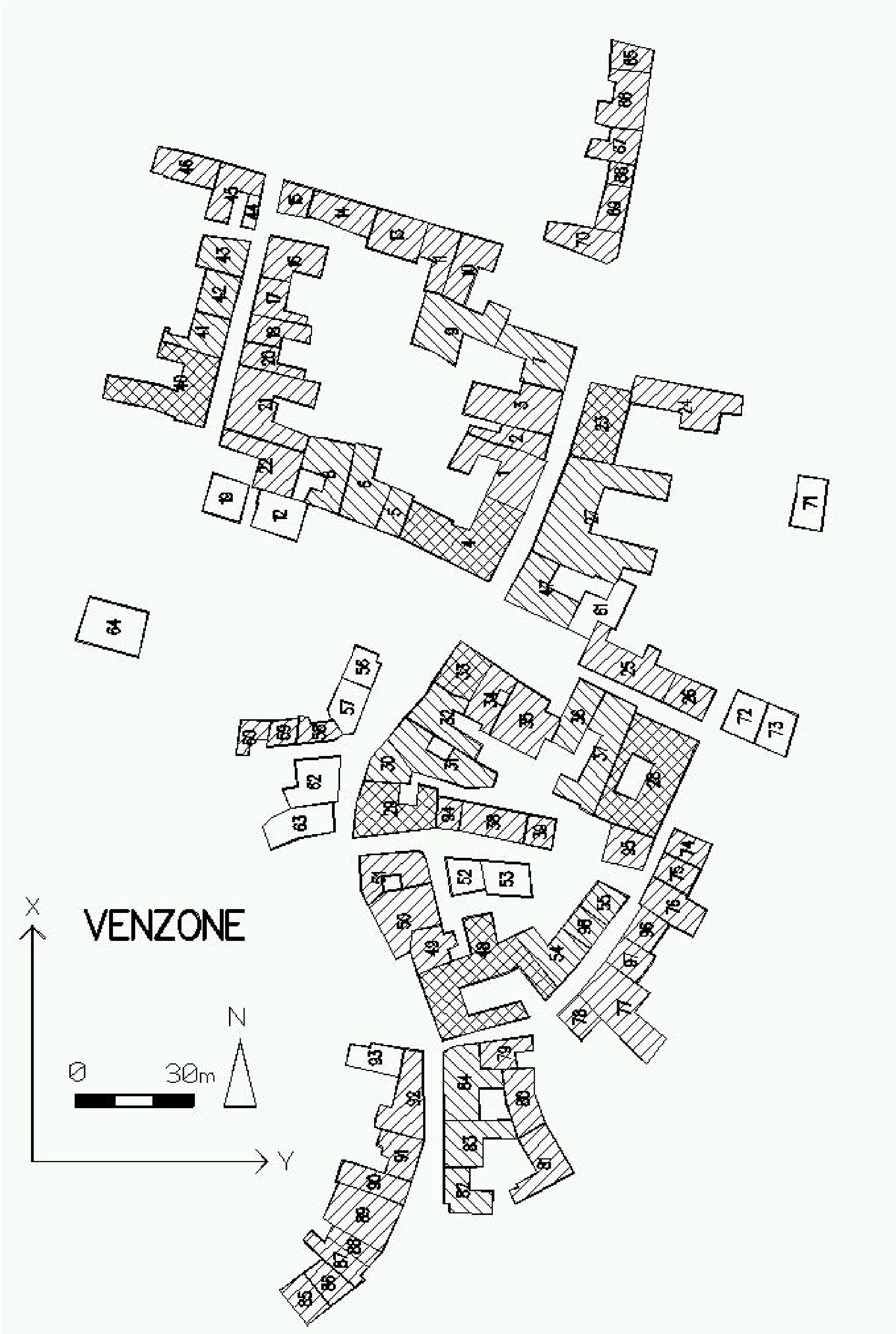


Fig. 11 - All analyzed buildings of Venzone are detected by the sheet number. The sketched polygons indicate the buildings array matched on the map. The crossing sketched polygons mean the overlapping of the building array with different orientation.

7.6 DISPLAYNG RESULTS BACK IN ARC/INFO

At the end of the analyses effected with the expert system and realized with Nexpert, the results saved in the attribute fields of the coverage are displayed by the graphic module of the Arc/Info: ARCPLOT. The aim of take back results in Arc/Info came from the great capacity of georeferring data of this system. A process structured in this way became transparent for the user that continue to handle data in the same original environment which generated them. A further facility is offered by queries process to combine multitemporal and multidimensional data in the Info module, or generate simulations by means of coefficients adjustment.

In this work we display back in Arc/Info the intrinsic and effective vulnerability values, the various typology of the identified buildings aggregation as *sub-blocks, buildings array* identified on the map and the positions of the single buildings in relation to the considered direction .

The vulnerability values in the two directions *X* and *Y* are plotted with the sketching of the *vulnerability ellipses* [9] by a written SML macro or by colour undercoats of the polygons that represent the plan of the buildings. Since an Arc/Info command to draw ellipses doesn't exist, a macro has been implemented that, given a building, reads the value of X and Y vulnerability, and with a simple mathematical relation, finds the points of the ellipse circumference with a fixed step.

8. RESULTS

The first group of rules described in paragraph 7.4 analyze the coverage containing the data of the historical centre of Venzone and identify the *buildings array* of the thirteen *sub-blocks* considered as well as the position of the single buildings in the analysis directions. In **Fig. 11**, the different *buildings array* 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 don't represent a *buildings array* for dimensional reasons (e.g. building 52 and 53)
- nearby buildings (e.g. building n° 93)
- the buildings that make interruption (e.g. building n° 61).

The *buildings array* that have been individuated are twenty-five, all of which are univocally referred to the cartesian reference as indicated in the lower left hand corner of the same figure. In the same way the positions of each building are indicated along two directions. The criterion of the choice of direction is critical because it is connected to the assignment of the street fronts direction made by the operator (paragraph 7.1), that are the initial candidates of a *buildings array* (paragraph 7.4). Note that the polygons without label are courtyards inside the buildings.

The table in **Fig. 12** illustrate the results on the table of the map described before. The fields SCH_X and SCH_Y contain the progressive numbers of the *buildings array* that are present inside 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 *buildings array* is indicated only in the direction in which the line is oriented; for all other cases the value zero is assigned.

Fig. 12 - Table of the results about the buildings array, positions and vulnerability. The buildings arrays are grouped with a contour box. The dashed box indicates the buildings not belonging to any array

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**

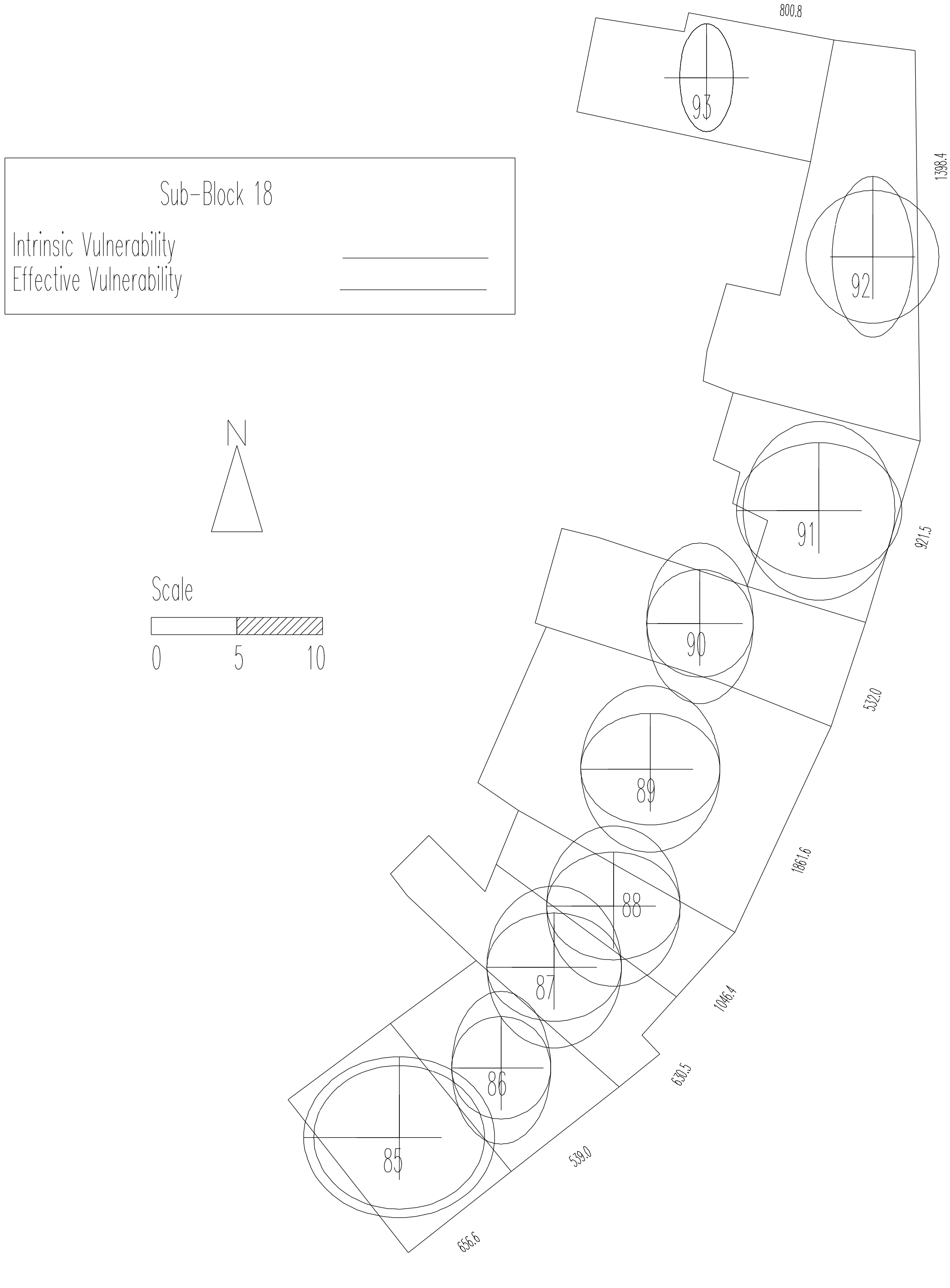


Fig. 13 - Vulnerability ellipse for all buildings of sub-block 18.

We shall examine in detail the results concerning sub-block n° 3. A total of 3 *buildings array* have been individuated:

- the first one include 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 is an angle building **Aa** due to the intersection of the *buildings array* 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 7.5 uses the information previously presented for the calculation of the vulnerability indices. The obtained results are indicated in the last four columns of **Fig. 12**: 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.

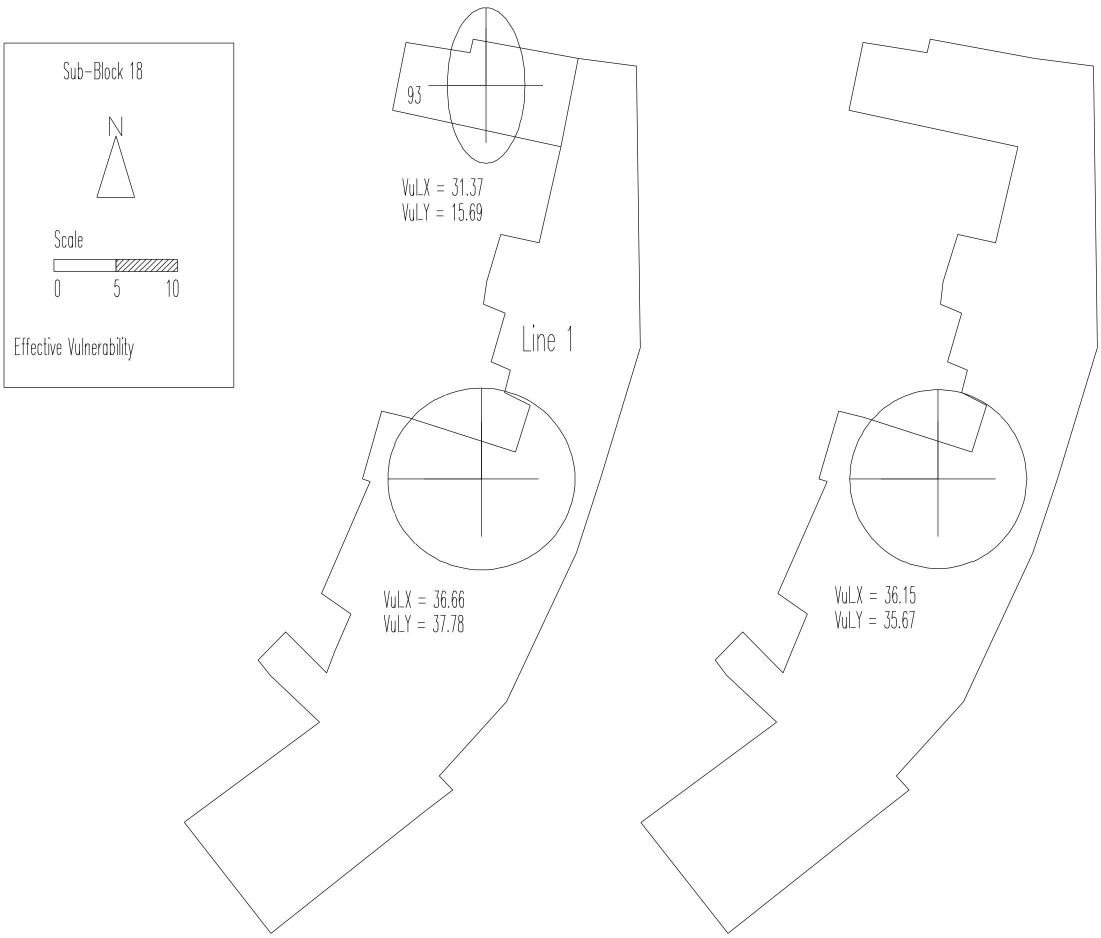


Fig. 14 - Effective vulnerability ellipse for sub-block 18.

In **Fig. 13** the entire *sub-block* n° 18 is represented with the vulnerability ellipse plot for every building. The axes dimensions , 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 *buildings array* (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 *buildings array* 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 a nearby position. It has to be reminded that the vulnerability of building n° 93 does not vary as it does not belong to the *buildings array*. The values at the 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 **Fig. 14**, on the left side, a single polygon points out the *buildings array* identified on *sub-block* n° 18, thus considered as a single structural element whose vulnerability is represented by only one overall 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 buildings array* 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 estimated by numbers, but it can result much more evidently if more complex sub-blocks are considered.

9. 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 in a UNIX environment, the full portioning of the coverages and the knowledge base will be an exciting experience (Maidment and Djokic, 1991) [5] in which the integration of the instruments being illustrated will enable a connection at the level of commands to both software environments.

An upper bound limit is the vectorial approach of the PC Arc/Info. Unfortunately, the structure of the system does not enable the 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 a conceptual description of the building shape. The availability of the whole set of data could permit a more efficient and profitable analysis for the vulnerability assessment of the structures by adding the shape analysis of buildings.

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 entire *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 and simulation of possible scenes of damage.

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