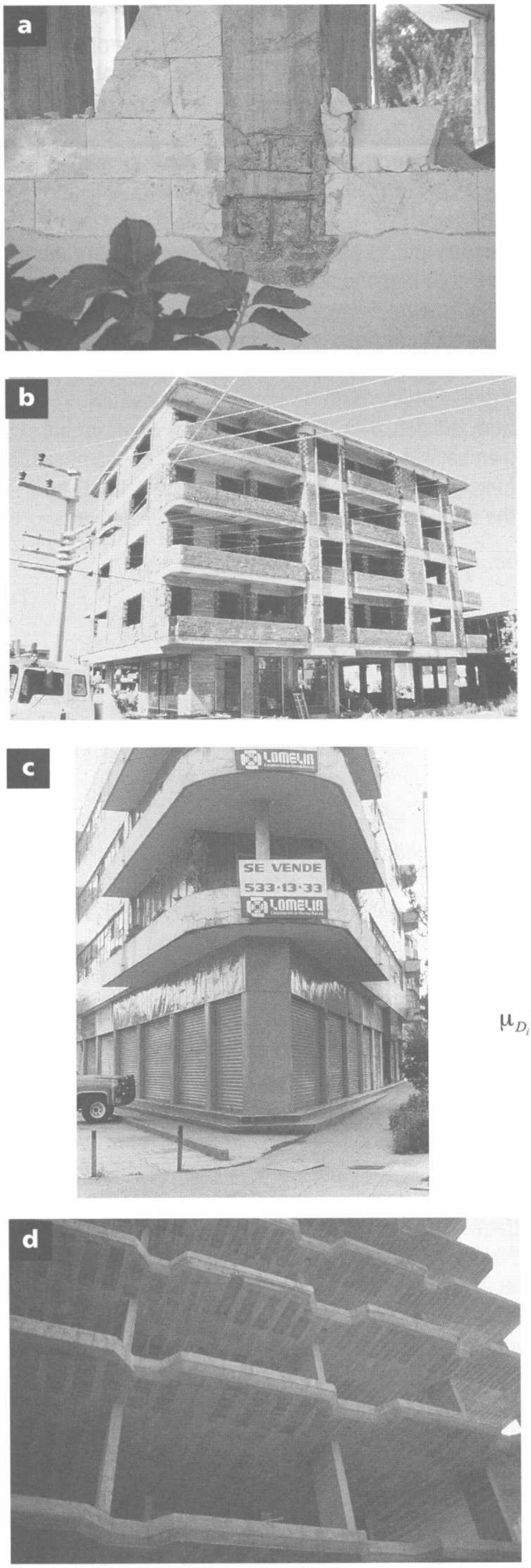

This model is a user-friendly computer program called Earthquake Damage Evaluation of Buildings, EDE. It offers aids for the inspectors, such as detailed descriptions and damage photographs. Recently, another computer program has been developed (ATC 2003). Unlike, this other program does not support the decision-making and basically its objective is to facilitate the data collection of the existing inspection form of ATC-20 (ATC 1989).

Description of the ANN

Input layer of the artificial neural network. The fuzzy sets for each element or variable i (for instance columns, walls or beams) in the input layer are obtained from the inspector's linguistic qualifications of damage Dj at each level j and its extension wj. The damage extension, or percentage of each damage level in each element, varies from 0 to 100 and it is normalized

$$w_j = \frac{D_j}{\sum_N D_j}, \sum_N w_j = 1 \qquad (1)$$

The accumulated qualification of damage Di for each variable is obtained as the union of the scaled fuzzy sets, taking into account the damage membership functions $mDj(Dj)$, and its extensions or weights assigned by the inspector

$$D_i = (D_N \cup D_L \cup D_M \cup D_H \cup D_S) \qquad (2)$$

$$\mu_{D_i}(D) = \max\left(w_{N,i} \times \mu_{D_N}(D_{N,i}), \ldots, w_{S,i} \times \mu_{D_S}(D_{S,i})\right) \qquad (3)$$

The union in the theory of the fuzzy sets is represented by the maximum membership or dependency. By means of defuzzification, using the centroid of area method (COA), a qualification index Ci is obtained for each variable of each group of neurons

$$C_i = \left[max\left(w_{N,i} \times \mu_{D_N}(D_{N,i}) \ldots, w_{S,i} \times \mu_{D_S}(D_{S,i})\right)\right]_{centroid} \qquad (4)$$

Figure 5
Pre-existent conditions:
a) Bad construction quality
b) Vertical shape irregularity: soft floor
c) Plane shape irregularity
d) Bad structural configuration: lack of frame continuity

Each variable has predefined the basic membership functions for the fuzzy sets corresponding to the five possible levels of damage. The linguistic qualifications change in each case. Figures 6 and 7 show some examples of the data input of the computer program.

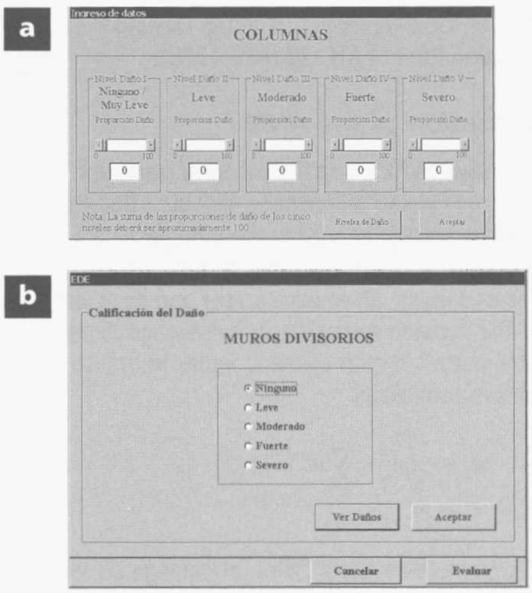

Figure 6. Input of the damage qualifications a) Damage extension at each damage level for a structural element b) For a non-structural element

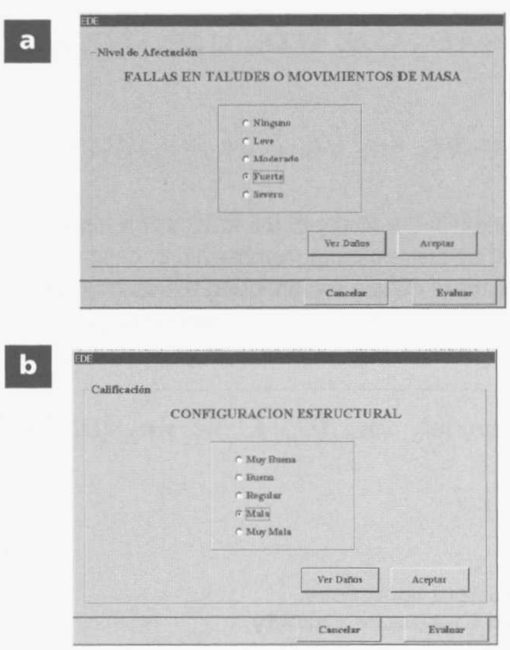

Figure 7. Input of the qualifications for ground conditions and pre-existent conditions a) Landslides and ground failure b) Structural configuration

Intermediate or hidden layer of ANN. This layer has four neurons corresponding to each group of variables: structural elements, non-structural elements, ground conditions and pre-existent conditions. Figure 8 shows a general scheme of the evaluation process. In this neural network model, the inputs of the four neurons are the qualifications Ci obtained for each variable of the each group of neurons and its weight Wi or degree of importance on the corresponding intermediate neurone. These weights were defined with the participation of experts in earthquake damage evaluation. Using these qualifications and weights for each variable i, a global index could be obtained, for each group k, from the defuzzification of the union or maximum membership of the scaled fuzzy sets. The membership functions $mCki(Cki)$ and their weights Wki show the notation for the group of structural elements.

$$I_{SE} = \left[\max\left(W_{SE1} \times \mu_{C_{SE1}}\left(C_{SE1}\right), \ldots, W_{SEi} \times \mu_{C_{SEi}}\left(C_{SEi}\right)\right)\right]_{centroid} \qquad (5)$$

$$\mu_{CSE}(C) = \max\left(W_{SE1} \times \mu_{C_{SE1}}\left(C_{SE1}\right), \ldots, W_{SEi} \times \mu_{C_{SEi}}\left(C_{SEi}\right)\right) \qquad (6)$$

The groups of variables related to ground and pre-existing conditions are optional, thus they can be or can be not considered within the evaluation. If this happens, the habitability and reparability of building is assessed only with the structural and non-structural information.

Output layer of ANN. In this layer, the global indices obtained for structural elements, non-structural elements, ground and pre-existent conditions correspond to one final linguistic qualification in each case. The damage level (qualitative) is obtained according to the "proximity" of the value obtained to a global damage function of reference. The training process of the neural network is achieved in this layer. The indices that identify each qualitative level (center of cluster) are changed in agreement with the indices calculated in each evaluation and with a learning rate. Once the final qualifications are made, it is possible to determine the global building damage, the habitability and reparability of the building using a set of fuzzy rule bases.

Training process of the ANN

The neuronal network is calibrated in the output layer when the damage functions are defined in relation to the damage matrix indices. In order to start the calibration, a departure point is defined,

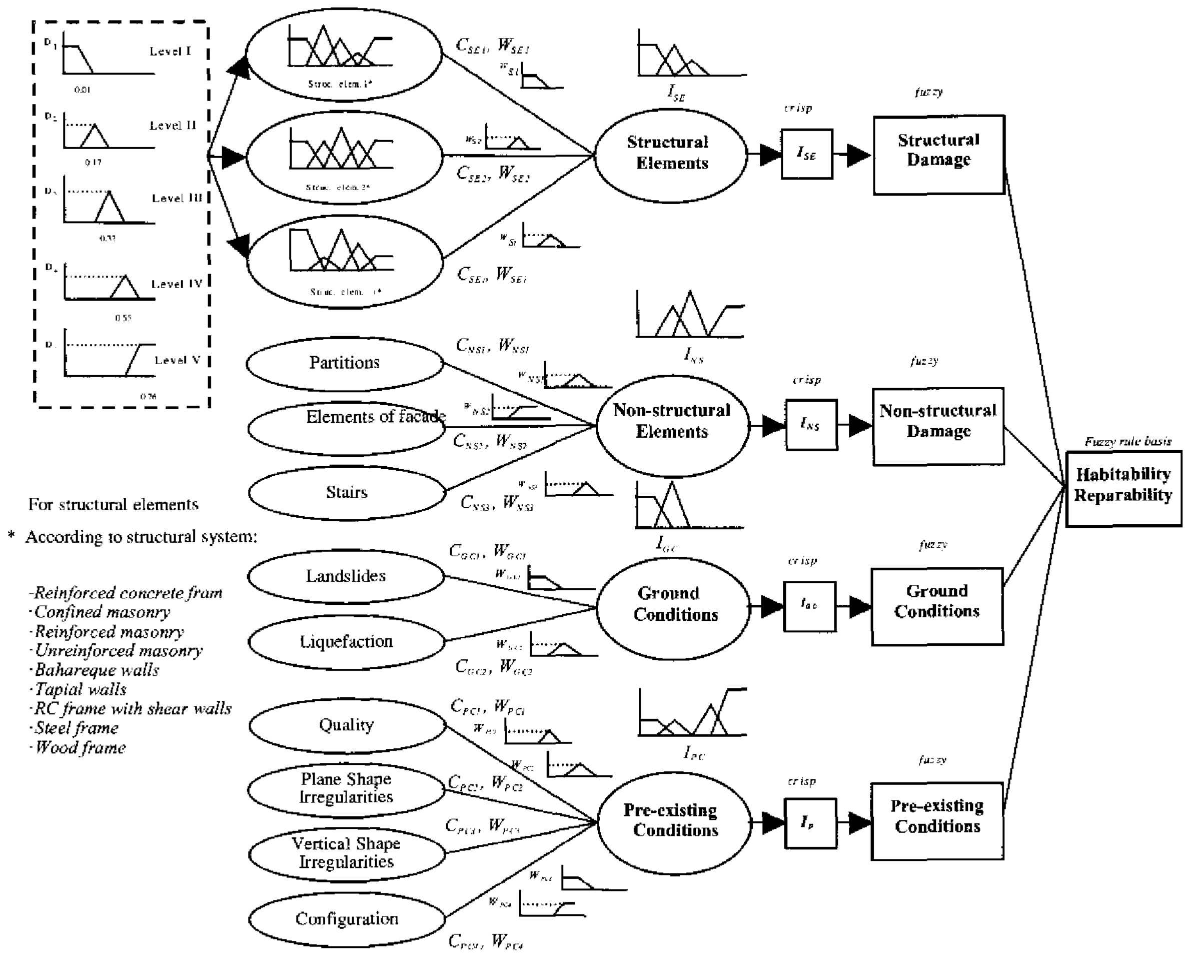

Figure 8. Structure of the proposed artificial neural network

that means the initial indices of each level of damage. The indices proposed by the ATC (1985), Park, Ang and Wen (1984), the fragility curves used by HAZUS (FEMA 1999), and the indices used by Sanchez-Silva and García (2001) have been considered. The values of these indices correspond to the center of the area for every membership function related to each damage level. Table 3 shows the indices proposed in this work.

Damage Level	Park, Ang and Wen	Sanchez-Silva	Proposed
Very light	< 0.10	0.07	0.10
Light	0.10 – 0.25	0.175	0.20
Moderate	0.25 – 0.40	0.325	0.35
Severe	0.40 – 0.80	0.6	0.60
Destruction	>0.80	0.8	0.90

Table 3. Comparative table for damage indices

Some authors consider that collapse occurs for a value equal to 0 8 and others propose a collapse threshold of 0.77. Therefore, a value of 0 76 has been selected to describe the destruction level index or collapse In the selection of the damage index, the author decided to be conservative, since the indices corresponding to severe and moderate damage have been highly discussed, and doubts exist on whether they should be smaller.

The calibration is performed for each damage level and only the indices corresponding to the groups of variables considered in each case are calibrated. The network learning is made using a Kohonen network

$$I_{kj}(t+1)=I_{kj}(t)+\alpha(t)\left[I_{kj}(t)-I_{kj}\right] \tag{7}$$

where Ikj is the value of the index of the variables group k recalculated considering a learning rate a, a function with exponential decay, and the difference between the resulting index of the present evaluation and the previous indices in each damage level j. The learning rate is defined by

$$\alpha(t)=0\ 1\times exp(-0.1\times t) \tag{8}$$

where t is the number of times that has been used the index that is calibrated. The damage evaluations made after the Quindío earthquake in Colombia (1999) were used for training.

Fuzzy rule bases for decision-making

The building habitability and reparability are assessed based on previous results of damage level of the structural and non-structural elements, the state of the ground and pre-existent conditions. The global level of a building damage is estimated with the structural and non-structural damage results. This has five possible qualifications: none, light, moderate, heavy and severe damage The global building state is determined taking into account the rule bases on ground conditions, and by this way the habitability of the building The linguistic qualification for the building habitability has four possibilities usable, restricted use, dangerous and prohibited. They mean habitable immediately, usable after reparation, usable after structural reinforcement, and not usable at all The building reparability depends besides on other fuzzy rule bases: the pre-existent conditions. The building reparability has four possibilities: not any or minor treatment, reparation, reinforcement, and possible demolition.

References

ATC, (1985) Earthquake damage evaluation data for California, ATC-13, Applied Technology Council, Redwood City, California

ATC, (1989). Procedures for postearthquake safety evaluation of buildings, ATC-20, Applied Technology Council, Redwood City, California.

ATC, (2003) Users manual Mobile postearthquake building safety evaluation data acquisition system (Version 1 0), ATC-20i, Applied Technology Council, Redwood City, California.

FEMA, (1999) Earthquake Loss Estimation Methodology HAZUS, Technical Manual, Vol I, II and III, First edition 1997, National Institute of Buildings Sciences of Federal Emergency Management Agency, Washington.

Sanchez-Silva, M. and L García, (2001). Earthquake Damage Assessment Based on Fuzzy Logic and Neural Networks, EERI Earthquake Spectra, Vol 17, N 1, February, pp. 89-11 2. Oakland, California

Y J Park, A Ang and Y Wen, (1984). Seismic Damage Analysis and Damage-Limiting Design of R.C. Buildings, Structural Research Series, Report No 516, University of Illinois at Urban-Champaign

How does your project address the links between poverty and disaster risk reduction in developing countries?

The disasters generate poverty and the poverty generates disasters The constructions of the low-income socioeconomic layers are the most vulnerable and therefore they are more affected when earthquakes happen In this sense the benefits of this project are more for the people that, as result of a suitable damage evaluation, are protected in their lives, avoiding they occupy buildings at risk, or protecting their patrimony, avoiding the unnecessary demolition of their houses when in fact they do not threaten ruin In any case, this project contributes with an innovating tool, from the technical point of view, that will be useful for all socioeconomic layers of a community affected by an earthquake, both in developing as in developed countries.

How will your project be sustainable beyond these first six months?

The tool developed into this project is now a component of technical support within the Program of Building Damage Evaluation that Asociación Colombiana de Ingeniería Sísmica (AIS) is coordinating in the cities of Manizales and Bogotá (the latter in process of implementation, phase II) The AIS-400 Committee, related to Vulnerability of

Buildings and Damage Evaluation will promote the program in other cities of the country in the next years. Also, together with the Advisory National Commission of Seismic and Volcanic Risk and the National Commission for Earthquake Resistant Building Code, AIS will promote a unified national methodology. This methodology of national level will include the Expert System, EDE developed in this project like a key tool for the preparedness, training and response of the engineers in support to the National System for Disaster Prevention and Risk Mitigation of Colombia, in case of an earthquake anywhere within the country.

How will your project have ownership among a broad community and institutional base?

Initially the project was developed as part of the Program of Damage Evaluation developed for Manizales city and now for Bogotá, under the direction of the organizations in charge of the prevention and attention of disasters (or disaster risk management) in each city, with the technical support of AIS. Although the project was developed with an academic scope, from the beginning it was proposed within the frame of the institutional action and within an existing program of preparedness for the damage evaluation in case of an earthquake in a city interested in the subject (Manizales). Due to the outcomes and advances, a second city (the capital) was interested in the Expert System, object of this project, for its adoption as official tool to support the building evaluations in case of an earthquake. At present a phase of training is implemented and involves hundreds of engineers, several universities and numerous public organizations. In the two cities a remarkable advance has been obtained that, like a replica, surely other cities and the national level will follow.

What are the components of learning in your project?

The project corresponds to a highly technical outcome where advanced Computational Intelligence (CI) techniques have been explored, like the fuzzy logic and artificial neural networks. This tool was developed to face a real problem of seismic security of remarkable complexity, such as the decision-making on habitability and reparability of buildings affected by earthquakes it is. The developed tool using these techniques improves the effectiveness of the damage evaluation and risk of the constructions, avoiding that non-expert people evaluate in a wrong way the level of security of buildings. Decision-making about the possibilities of building occupation and reparation, by this way, is more reliable and quick, favoring the efficient management to attend the community in case of a seismic disaster.