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INTELLIGENT VIRTUAL REALITY OF A METROPOLIS DEVASTATED BY EARTHQUAKES

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Abstract

The reconstruction of a city that has been devastated by an earthquake requires the intelligent management of resources and the establishment of work directions that return, as quickly as possible, the largest number of residents to their routine life. The most important difficulty arising in the initial reconstruction after strong events is to find the best assignment of available resources to operational areas, being one of the aspects that authorities must be deal with immediately, the recovery of buried facilities that conduct water, gas, or hydrocarbons. For approach to this problem, in this investigation a Virtual Reality-Dynamic Optimization Model is introduced. The proposal uses detailed 4D-descriptions of the regions with i) higher vulnerability to collapse, break or smash pipelines, ii) specific characteristics of the ground motions and soil properties, iii) strategic densities of superstructures/buried infrastructure and iv) low social resilience. This information is the feeding of a neural network that predict scenarios for a Virtual Reality engine. The resources and reparation/aid teams' functioning, for the tasks related to an effective response, can be simulated.

Keywords: Neural Networks, Virtual Reality, differential settlements, damaged pipelines, Mexico City clays, September 19th, 2017 earthquake.

1. Introduction

The September 19th, 2017, a M 7.1 earthquake (normal fault) hit Mexico City causing more than two hundred deaths, around 5,000 people injured, 230 collapsed buildings and more than seven thousand small houses where the damages required the intervention of geotechnics and structural specialists to determine safe conditions and to permit people to return to their homes. Exactly 32 years before (Sept 19th, 1985), a M8.1 event (subduction zone) had showed the fact that the city is built on the unstable and sinking ground of a dried-out lakebed that promoted a better geo-zonification of the risk. This devastating phenomenon caused more than 10,000 deaths, destroyed 30,000 buildings, and injured about 68,000 people. The functioning of the city was failed for months, the reconstruction took years, and led many to relocate from the most affected areas to the city's outskirts in search of the safety of the bedrock. The districts affected in these events were quite different and, because of this, the type of damage and the technical needs to manage the help activities were also distinctive. These experiences have undoubtedly shown that for designing an efficient post-earthquake relief plan, it must be recognized that Mexico City is particularly exposed because of its huge population and strategic importance for the country and that this vulnerability has grown the last years due to the expansion of the urban settlements in risky areas (nodules of extreme poverty), the environmental devastation, the deterioration of life levels, the economic activities concentration that require the transport of substances (water -potable and used- gas and hydrocarbons) by underground infrastructure, and the growing complexity of transportation process.

Despite the best intentions and the enormous efforts of the governments that have attended these emergencies, the situations dangerously evolved and the period in which the city was detained, and the population subjected to chaos, spread out for months (after Sept 19th, 1985 for years) damaging, primarily, the poorer and fragile (socially) population centers. Hereby, there is an increasing need for a holistic and more efficient natural disaster management NDM. In this investigation a neural-NDM, NNDM, process is presented. To preserve human live, the NNDM must be applied pre-, during-, and post-disasters. The knowledge about the irregularity of soils properties (and responses), earthquakes damage intensities, and the actions effectiveness (professional teams and their capacities) is used for training a set of neural topologies that predict the spatial variability of risk components. The exposure and vulnerability that are more related to the effects on the pipes (water, gas, and oil) are categorized from the impact of the post-failure secondary events.

In this investigation it is proposed a Virtual Reality, VR, engine to train and to administrate the three phases of natural disaster management: preparedness, response, and recovery. This VR instrument has the capability bridge the gap between knowledge and action with the necessary velocity and efficiency when disasters happen. Exploiting the scenarios reconstructed with the NNDM, the leaks care staff, first-responders, civilians, and city-planners can be prepared to work under a series of conditions built in virtual-life, expanding the learning experience. Also, the best communication routes are tested against combinations of truncated routes and collapsed systems to arrive, as quick as possible, at locations in most need of assistance. In this paper is used the Mexican experiences during the 2017 earthquake to show the automatic procedure for organizing people and distribute resources.

2. Neural Networks for the NDM

In a first stage, neural networks are used to construct the dynamic maps of key risk parameters to stablish priorities, the teams-reactions and the kind of engineers needed at every zone. For this module, called *Geo-descriptors,* the neural inputs are (Fig. 1)

- geotechnical (zonation, stratigraphic category, clay layer thickness),
- geological (relief, transitional categories, column category),
- seismological (seismogenic zone, magnitude, focal depth and epicentral distance), and
- topographical (level gradients, elevation category)

interpretations of the city and the output is the ground motion expressed as Peak Ground Acceleration PGA.

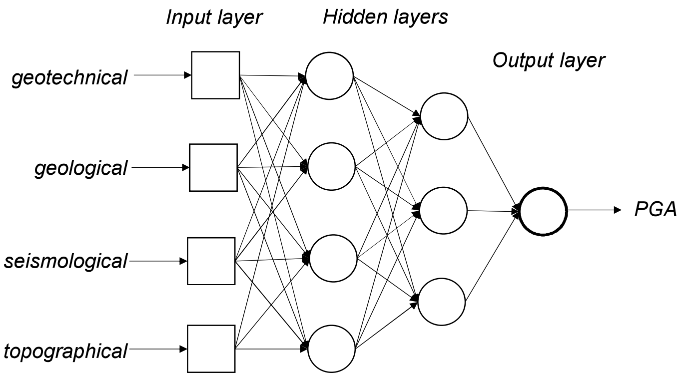


Fig. 1- General neural topology used to define the spatial variation of phenomena-intensity parameters (the input layer is referred to pixels and voxels in a geo-referenced environment).

This mapped information constitutes the spatial variation of the threat: *earthquake*. See Fig. 2 as an example of the results of this module. The September 19^{th}, 2017 event was analyzed using data from 48 stations that registered the movement. From these sites 10 acceleration stations were selected to test the network and the rest were left for training. Between the many different architectures tried, a Multilayer Feed Forward, backpropagation, 4-100x100-1 (inputs- hidden nodes- output) structure was considered the optimal. The predicted and actual values of PGAs, for the training and test validation samples, are very closer (Fig. 3). This neural model was used to construct the 2D variation on a grid every 50 m. The remarkable capacity of the NN for predicting the PGAs in the three different geotechnical zones can be seen. The collapsed buildings were concentrated around 120-240 cm/s^2 (Lake Zone on the border with the Transition Zone) but the highest levels of PGAs were generated in a not completely-defined geotechnical zone with evidence of considerable topographic effects (see red zones at southeast).

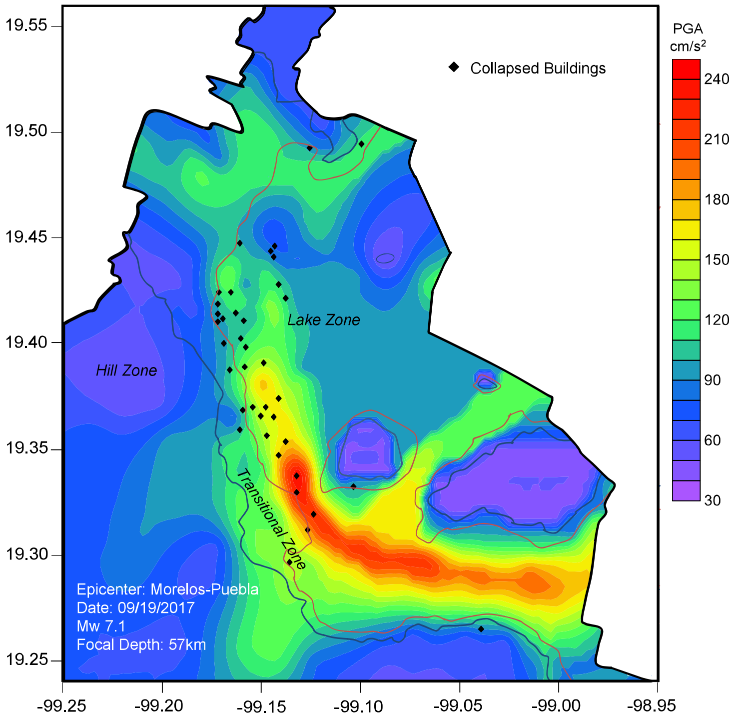
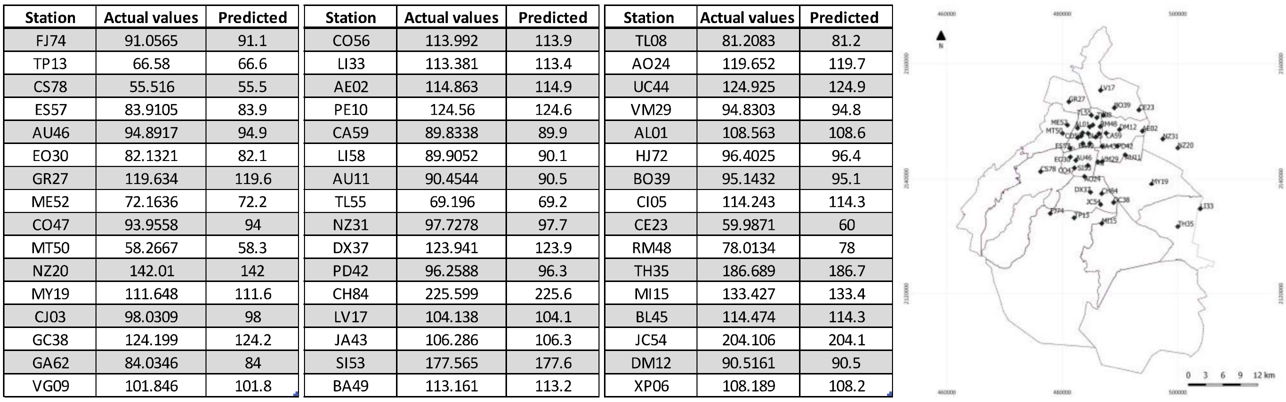


Fig. 2- PGA-neural distribution for September 19th, 2017 (Mw 7.1) Earthquake, in Mexico City.



Station	Actual values	Predicted	Station	Actual values	Predicted	Station	Actual values	Predicted
FJ74	91.0565	91.1	CO56	113.992	113.9	TL08	81.2083	81.2
TP13	66.58	66.6	LI33	113.381	113.4	AO24	119.652	119.7
CS78	55.516	55.5	AE02	114.863	114.9	UC44	124.925	124.9
ES57	83.9105	83.9	PE10	124.56	124.6	VM29	94.8303	94.8
AU46	94.8917	94.9	CA59	89.8338	89.9	AL01	108.563	108.6
EO30	82.1321	82.1	LI58	89.9052	90.1	HJ72	96.4025	96.4
GR27	119.634	119.6	AU11	90.4544	90.5	BO39	95.1432	95.1
ME52	72.1636	72.2	TL55	69.196	69.2	CI05	114.243	114.3
CO47	93.9558	94	NZ31	97.7278	97.7	CE23	59.9871	60
MT50	58.2667	58.3	DX37	123.941	123.9	RM48	78.0134	78
NZ20	142.01	142	PD42	96.2588	96.3	TH35	186.689	186.7
MY19	111.648	111.6	CH84	225.599	225.6	MI15	133.427	133.4
CJ03	98.0309	98	LV17	104.138	104.1	BL45	114.474	114.3
GC38	124.199	124.2	JA43	106.286	106.3	JC54	204.106	204.1
GA62	84.0346	84	SI53	177.565	177.6	DM12	90.5161	90.5
VG09	101.846	101.8	BA49	113.161	113.2	XP06	108.189	108.2

Fig. 3- Examples of predicted and actual values of PGAs for September 19th, 2017 (Mw 7.1).

After the 2017 seismic event, was precisely in this area to the southeast of the city, where Mexican authorities had to reconstruct more than two thousand of small, wrong-structured, small houses because of the enormous damages suffered when the seismic waves hit a fragilized soil (in Fig. 4 a summary of the cases to be attended in one of the most damaged municipalities). Sidewalks and pipelines (water) suffered the same effects. In addition to the extremely high accelerations, the vulnerability of the soils to the arrival of seismic waves was very high. The most superficial layers in this area suffer cracking and subsidence processes among the most alarming in the world. In areas with rapid urbanization and demographic growth, the prolonged exploitation of groundwater is causing the land to sink and to crack with the consequent dangerous impacts (Fig. 5). The after-effects on the operation of urban infrastructure are extremely costly. The periods of drought and torrential rains aggravate the manifestation of the collapse of the layers of soil, being the small buildings and buried facilities more fragile (due to construction deficiencies, poor technical conceptions, or aging / degradation of materials). In this research, the subsidence and cracking are studied as layers of the *Geo-descriptors* module using Machine Learning and Data Science tools. The susceptibility to sink-fracture is mapped and integrated into an urban spatial display.

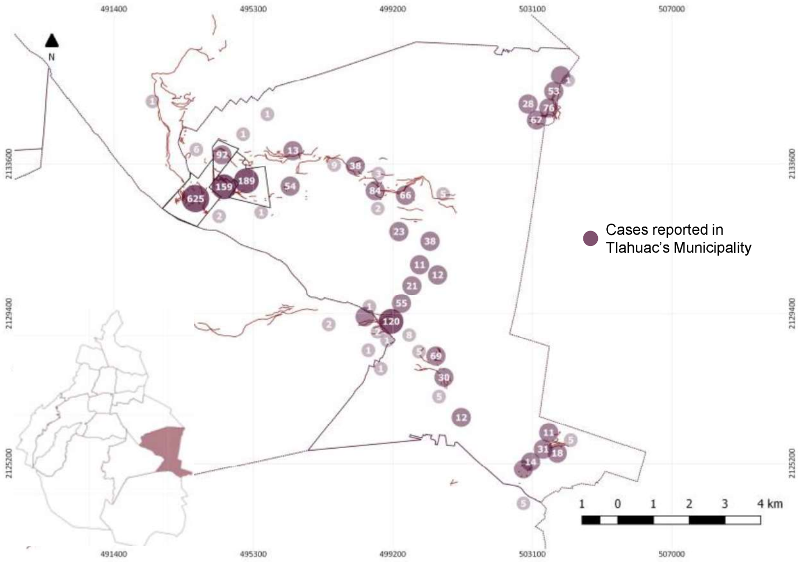
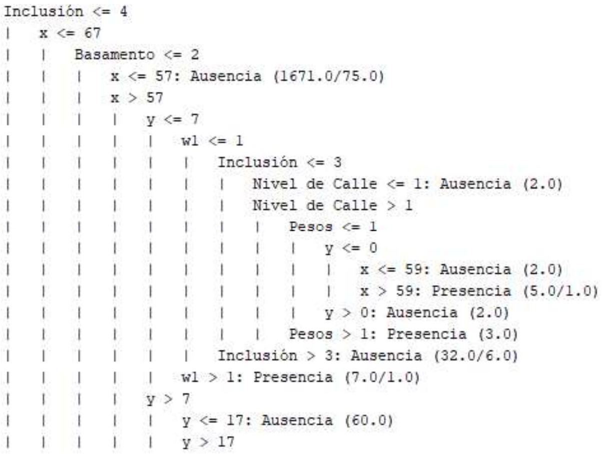


Fig. 4- Damaged houses to be attended in Tláhuac's Municipality, one of the poorest regions in the city. In the map the superficial cracks in soils are depcited using a solid line (red).

Fig. 5- The sinking phenomena and the derived effect on soils of the southern region in the City: cracking.

For clarifying the procedure, a study area was selected in a damaged suburb in the city. It was divided into 3645 cells, 10x10 m. With the analysis of 9 variables (Position in space (x, y), Inclusion, Groundwater Level, Heterogeneity, Structure weight, Foundation, Street level and Cracks) a CART was built to determine the relative influence of each one on the cracks' development. A part of the resulting tree is shown in Fig. 6. The analysis indicates as the driving node, the *Inclusion* (a non-continuous thin layer of semi-rigid material embedded in the plastic clay). Also, the *Position* is a decision node, it signifies the distance from the site to the water pumping wells (operating at relatively shallow depths). Finally, is the shape and depth at which it is the rigid base of the basin an important coupled parameter for the final decision fracture/not fracture. Using this analysis, the cracking susceptibility and exposition can be displayed in a map (Fig. 7).



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Inclusión <= 4
|   x <= 67
|   |   Basamento <= 2
|   |   |   x <= 57: Ausencia (1671.0/75.0)
|   |   |   x > 57
|   |   |   |   y <= 7
|   |   |   |   |   wl <= 1
|   |   |   |   |   |   Inclusión <= 3
|   |   |   |   |   |   |   Nivel de Calle <= 1: Ausencia (2.0)
|   |   |   |   |   |   |   Nivel de Calle > 1
|   |   |   |   |   |   |   |   Pesos <= 1
|   |   |   |   |   |   |   |   |   y <= 0
|   |   |   |   |   |   |   |   |   |   x <= 59: Ausencia (2.0)
|   |   |   |   |   |   |   |   |   |   x > 59: Presencia (5.0/1.0)
|   |   |   |   |   |   |   |   |   y > 0: Ausencia (2.0)
|   |   |   |   |   |   |   |   Pesos > 1: Presencia (3.0)
|   |   |   |   |   |   Inclusión > 3: Ausencia (32.0/6.0)
|   |   |   |   |   wl > 1: Presencia (7.0/1.0)
|   |   |   |   y > 7
|   |   |   |   |   y <= 17: Ausencia (60.0)
|   |   |   |   |   y > 17
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Fig. 6- Classification tree for defining the development of cracks in the soils (given certain parametric combinations).

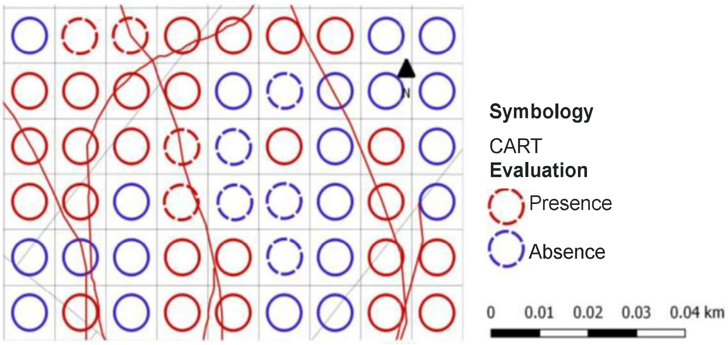

Fig. 7- Categorization of pixels with CART: presence / absence of cracking.

In the second stage, the module *Anthropo-descriptors* is defined under discoveries from data science. Analyzing 12 parameters that qualify the aptitudes of a community to resolve post-earthquake emergency situations and 5 variables that express the existence of dangerous buried infrastructure, it was concluded that the following are the most important when it comes to the efficient exercise of actions and economic resources:

- higher vulnerability to collapse, break or smash water-gas pipelines,
- strategic densities of not suitable superstructures (poverty nodes)

- population density (high rate),
- aid institutes (in a predetermined radius, existence of)
- available human resources (specialized teams concentrated in sufficiently close regions).

The outputs are categories geo-referenced as shown in Fig. 8. The simulation and prediction of scenarios can be now developed combining the *Geo*- and *Anthropo descriptors*. The design of the global outcome is flexible and adaptative. For example, for the 2017 earthquake, it is possible to analyze the areas to which the leak repair teams should be sent as a first reaction given the situation of vulnerability of the pipes, the number of people affected and the intensity of the ground motions (Fig. 9). If, on the other hand, the stage is preparation before a phenomenon strikes, the regions that have high vulnerability and lack of rescue centers or specialized personnel for the type of post-earthquake consequences for each region can be analyzed, for example in one of the municipalities, Tláhuac, in which the susceptibility to fracturing is very high, there are no capacities to determine the health of the structures or to manage the rescue teams from the perspective of those who recognize the stability of the collapsed elements or semi-collapsed.

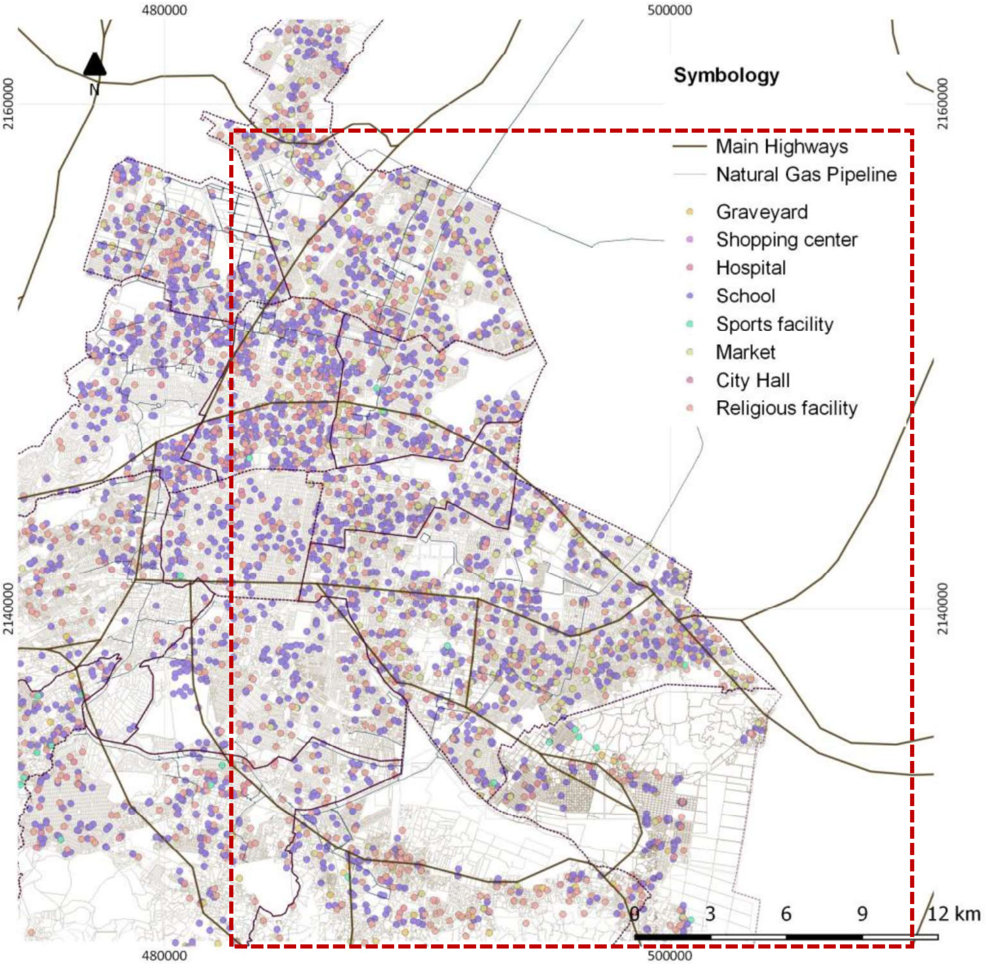

Figure 8. Output categories.

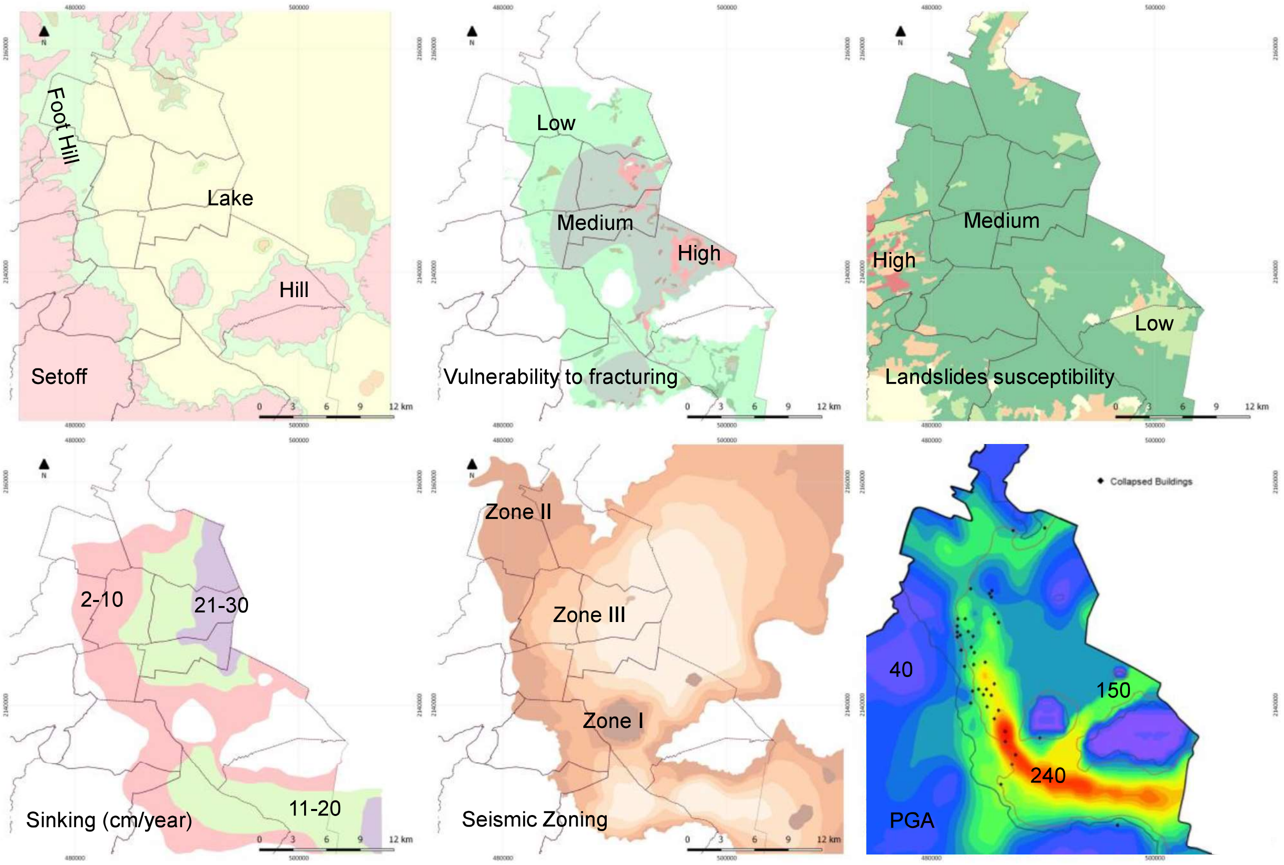

Fig. 9- Regions that have high vulnerability.

3. Virtual Reality

Virtual Reality VR creates a portal through which citizens, government administrators and specialists can experience a NN-designed Mexican capital. Unlike other interfaces, in which the user views a screen while remaining otherwise tethered to their contextual physical world, the NN-VR engine allows users to experience a whole different universe. VR systems induce us to believe we belong to a specific environment. To reach this, the system must mislead the parts of the brain that perceive vision, motion and other senses. For this research, the NN-VR system was designed to work with Head Mounted Display HMD, responsible for trapping our vision. To understand how an HMD operates, first it is necessary to describe how human vision works. Basically, each of our eyes captures 2D images of the environment we are looking at, but our brain is the processor that does the trickery to perceive what we see as 3D using many other information like spatial audio, interaction with the environment, previous experiences etc [1-3]. VR systems use the principle of stereoscopic vision to simulate the perception of depth and 3D structures. In this way the VR system renders a stereoscopic image on the display of the HMD in a velocity that avoid any perceived lag that might break the illusion or, worse, lead to the nausea that is often associated with poorly performing VR. The HMD includes lenses that augment our eyes to converge the images, so the VR system renders on the display and the lenses converges and corrects distortions in order our brain finally perceives something "real" with a sense of depth. After display, the next essential trick for making the brain believe it is in another place is to track movements of the head and update the rendered scene without any lag. To increase the degree of immersion this VR system allows the user to interact with the virtual environment. This asks for specialized input devices, which can be as simple as a magnetic button in Google Cardboard or as advanced as hand and body-tracking sensors that can recognize motion and gestures (like Leap Motion, HTC Vive body tracking system, etc).

The applications of VR to Civil and Architectural Engineering projects have concentrated on visual simulation of the construction process, design management, and geometrical representations of the civil works together with scheduling data (the 4D = 3D + time). Undoubtedly, one of the engineering branches that most successful VR-products have developed is geology, with noteworthy studios for 3D data visualization, geo-interpretation software for field campaigns, digital outcrop models with multiple attributes from any point cloud type dataset, among others. In this research, both aspects are exploited to achieve the defined objectives.

Preparedness. Because of the character of natural disasters, it is impossible to train under real-life conditions, limiting the learning experience of first-responders, civilians, and infrastructure designers. With the NN-VR engine the involved can be trained in situations that cannot be simulated in any other way. Simulations are about first-responders' reactions for specific scenarios: 1. in extreme vulnerable communities, analysis of evacuation routes, 2. recognition of structural pathologies within residential homes and multi-family buildings, 3. strokes of strategic reviews of water and gas pipelines and 4. definition of alterations in soil masses susceptible to cracking and / or sliding (Fig. 10).

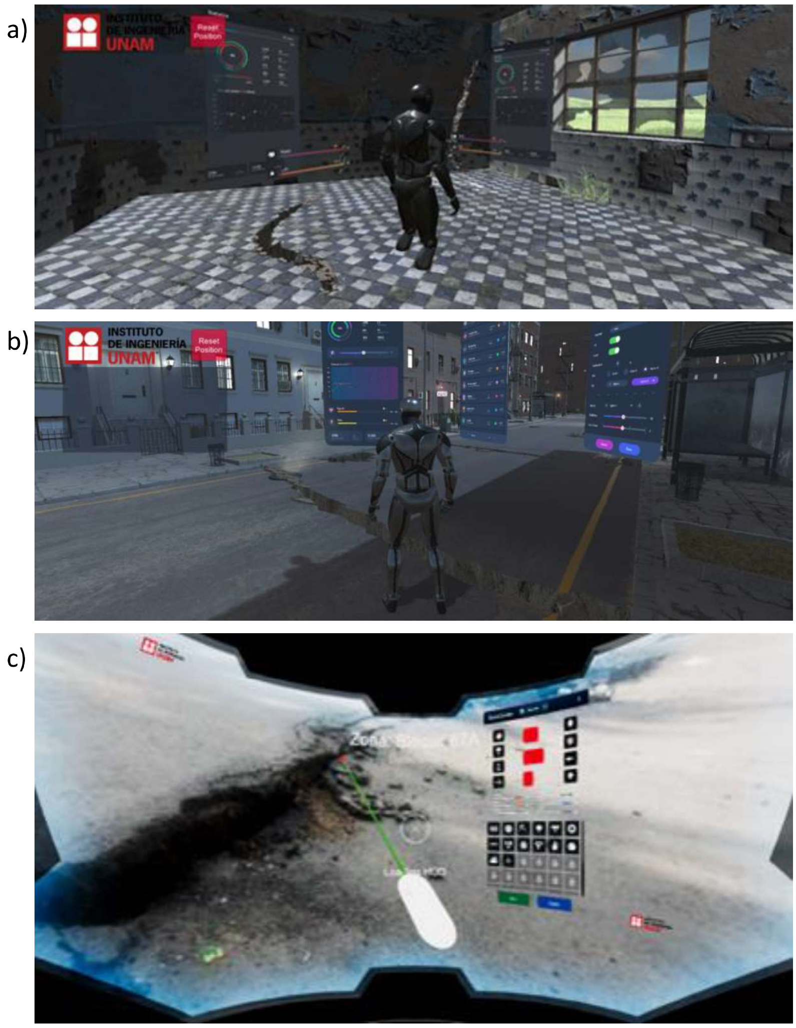

Fig. 10- Some examples of the training using VR, a) the structural and geotechnical engineers experience the pathology of a damaged house, b) geo-engineers can be trained under different manifestations of cracked soils to separate the origins, c) cracked soils under a superficial foundation is analyzed by many experts and the personal in field, using the possibilities of VR.

Exploiting the VR tool, the ability to evaluate risks is increased and the reaction time gets reduced. The immersive experience of an earthquake (during the shaking and / or immediately after it has happened) is simulated in locations where the predictions point out fragile infrastructure coupled with danger zones (susceptible soils). In this way the teams (engineers, designers, government, and urban planners) can integrally evaluate cause-effects and directly determine how many resources the city and community need to improve resilience for future disasters, which is one of the most effective long-term strategies [4]. These virtual collaborative immersive spaces allow different experts from all over the world to work together in the same virtual environment, creating more enhanced and coordinated solutions.

Response. When the earthquake has happened it is essential, for an adequate recovery, that the response be in a timely manner. Since the work teams have been trained in virtual parallel situations, response memory has been developed so the first responders have gathered knowledge about possible disaster scenarios. Furthermore, when is applied in *response* stage, the VR (and information in Augmented Reality AR) enhances the understanding of different elements in infrastructure because through communication devices (helmet or glasses) specific indications are made according to what a monitor in head offices observes through his eyes. It is also possible to send to the personal in field, data on geotechnics, geology, structuring or pipelines characteristics that have previously been stored in the geo-referenced DataMart (Fig. 11).

Consequently, response is improved because several experts can be connected to the moment of decision making. During the recognition campaigns after the 19th, September 2017 event, these technologies were applied -as prototype- to check gas installations and cracked foundations. The field-teams used VR-glasses and directly were coupled with people in command who could, in turn, develop more accurate responses and sending instructions for repairs and closure of houses and buildings (signaling for demolition or intervention of other more specific structural-repair teams). Beside it was proven that the data integration conditions from various sources, such as video and drone-mounted sensors (360° cameras and temperature-pressure sensors), ran very naturally and efficiently.

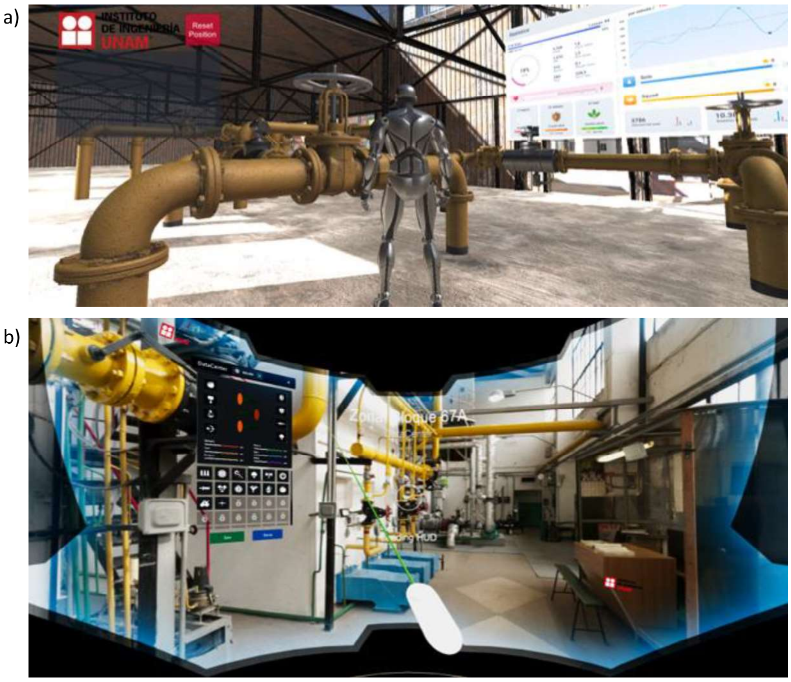

Fig. 11- Using the helmet for VR, the analyst can verify the situation of strategic (and dangerous) installations, as gas pipelines, a) the VR-AR environment of a valve cabin is studied, b) VR-glasses are used in a lab for integrating what is being happening in site with additional information stored in a DataMart.

Recovery. Through the improvement of preparedness and response, also the recovery phase advances and the time to return to an equilibrium state decreases significantly. The enhanced visualization of the aftermath facilitates recovery by pointing out the most critically damaged areas and identifying missing infrastructure. In this prototype the spatial analysis of damages (on natural and anthropic environments) versus affected population is useful to create operative programs. Recovery plans are improved when the simulations are developed before the resource suppliance is coordinated. The collaborative ability of VR enables multiple teams to work on one virtual environment at the same time, contributing expertise from different fields and perspectives. Also, in virtual environments, damaged buildings and critical infrastructure can be recreated in an inexpensive way to reconstruct and display possible ways to recovery.

4. Conclusions

For gathering a more sustainable, equal, and inclusive world with no one left behind, there is an urgent need to transform the current unsustainable interactions within social ecological systems SES into ones that are harmonious. The role of emerging technologies in achieving harmonious SES interactions is crucial. The tools presented in this investigation show how they can be used to enhance social-ecological resilience to environmental disruptions, particularly earthquakes threat. It has been showed how NN and VR can enhance natural disaster management (NDM) to close the gap between knowledge and action but also to be efficient and fair in serving the population in danger or that has been severely damaged (in person or property).

VR technology provides visual simulations to create a vivid first-person experience. Temporal, spatial, and social differences are lowered by immersing people into a certain location or experience. This immersion can be exploited in the three phases of NDM: preparedness, response, and recovery. NN+ VR is an innovative addition to NDM as it provides a non-destructive and safe technique to recreate natural disasters. The simulation of future conditions using the parametric relationships found by NN improves the understanding of what kind of damage is caused, how to better prepare, and shows the possible ways to recovery.

The relationship between humans and nature is becoming more fragile and is getting disrupted more frequently. The application presented here is just an example of using structured innovations for an improved NDM, the systematic process to save human lives.

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