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Whereto with Earthquake Risk Management: The Resultant of Sensor-Web and Web-GIS Could Show the Way

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Abstract—**Among the many kinds of natural and man-made disasters, earthquakes dominate with regard to their impact on the urban built environment (socially and economically). For any kind of disaster, there is a five-phases lifecycle (i.e., response, recovery, mitigation, prevention, preparedness) known as Emergency Management and Disaster (Crisis) Risk Management Cycle (DRMC). A fundamentally substantial tool to cover and support DRMC is GIS (Geographical Information Systems), especially Web-GIS. In this paper, several new technologies that are already actively involved (or indicated "ready" to engage) in the field of GIS are summarized. A re-consideration of the GIS-status in relation with such technologies (especially geosensors, wireless sensor networks and Structural Health Monitoring techniques) is suggested. The results of such a re-consideration will surely lead to a wide upgrade regarding the rules and specifications related to earthquake-disasters, and the effectiveness of GIS in the emergency management of earthquakes as well.**

Keywords—**Emergency Management and Disaster (Crisis) Risk Management Cycle (DRMC); Earthquake Risk Management; Structural Health Monitoring; Geosensors; Wireless Sensor Networks**

I. INTRODUCTORY REVIEW

There are several definitions of the terms: disaster, hazard, risk, emergency, crisis, with a certain degree of synonymity among these terms. The United Nations defined «**Disasters**» as *'A serious disruption of the functioning of a community or a society causing widespread human, material, economic and environmental losses which exceed the ability of the affected community/society to cope using its own resources'*.

«**Disaster**» is a term which has its direct roots to the ancient Greek word «**δυσαστρία**». This Greek word, with clearly astrological base, originally meant an unlucky constellation (or combination of positions) of the stars. Disaster implied that when specific stars, due their temporal position, form a 'malefic' (as old generations of astrologers used to say) constellation then consequently, a bad event, a grave misfortune was going to happen.

On the other hand, a «**Hazard**» is '*a situation which poses a level of threat to life, health, property or environment*'. When humans act, any of their action exposes them to hazards. A hazard does not necessarily put humans at risk. Most hazards are dormant or potential, with only a theoretical risk of harm. Where «**Risk**» is '*the probability and severity of loss linked to hazards*'. However, once a hazard becomes 'active', it can create an emergency situation. «**Emergency**» means *'a sudden and unexpected occurrence which requires urgent attention'*, in other words *'a situation that poses an immediate risk to health, life, property or environment'*. Finally, «**Crisis**» is *'a highly volatile dangerous situation requiring immediate remedial action'*.

In today's simplified words, a Disaster is *'the impact of natural or man-made (or a combination of both) hazards that negatively affects society or environment'*. The two main general categories of disasters are:

a. **Man-made (or human-made or anthropogenic):** Hazardous materials, Social-Sociological, Technological, Transportation;
b. **Natural:** Astronomical-Cosmic, Biological, Geological, Meteorological-Weather.

A not sedulous Web and bibliography investigation combined with a rough calculation of the number of disasters belonging to the above two main categories (and their eight sub-categories), have as outcome more than fifty (50!), where a good number of them belongs to more than one categories understandably (e.g. a flood or a sea-level change, plausibly belong both to geological and meteorological categories. Furthermore, a mine fire could have either technological or geological causes and so on).

Disasters will always happen, this is an axiom. Therefore there will always exist a double target concerning the minimization of: (a). The human losses and (b). The consequences to the natural and built environment [10].

One of the most important natural disasters, which are the main "target" in this paper, are earthquakes. From a clearly geophysical point of view, «**earthquake (seismic) risk**» is *'an assortment of earthquake effects that range from ground shaking, surface faulting, and landslides to economic loss and casualties. The probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time'* [2].

Finally, speaking about «**Seismic Risk Management**», it is about *'a bunch of certain parameters* *governing the effectiveness for the confrontation of devastating phenomena and consequently, the protection of life, health and fortune of citizens as well as protection of building reserve and infrastructure'.*

II. EMERGENCY MANGEMENT AND DISASTER (CRISIS) RISK MANAGEMENT CYCLE (DRMC)

In simple words, «**Emergency Management**» is *'the discipline dealing with risk and risk avoidance'* [9]. There are several methods, procedures, protocols and strategies of emergency planning [3]. There are five phases (Fig. 1) in every disaster´s life-cycle (i.e., response, recovery, mitigation, prevention, preparedness). This cycle is a "clockwise perpetual" cycle.

FEMA [9] considers the same cycle with four phases (i.e., mitigation, preparedness, response, recovery) and, generally speaking, this cycle could be found in other publications or in the Web with some minor modifications, additions or consolidations regarding its phase-components.

III. EARTQUAKES AND THE USUAL "TOOLS" FOR THEIR LIFE-CYCLE

One of the most destructive natural hazards known to mankind are considered earthquakes, with evident impact on urban infrastructure and human casualties. All the responsible authorities have to act fast and efficiently meet the resultant demands. Furthermore, these authorities are pushed, to implement short-term emergency powers and long-term relief measures, as well. The "umbrella-authority" which has the supervisory duties to enable and manage all these, is Civil Protection (also described as Civil Defense). Nowadays, the most successful «tools» for earthquake emergency/risk management belong to the science of Geomatics and particularly in its field of GIS (Geographical Information Systems), even better in the sub-field of Web-GIS which «breathe and live» definetely into the Internet. Such systems have all the credentials to cover and support the whole life-cycle of any kind of disaster (in our case earthquakes) with remarkable efficiency and effectiveness [7], [8], [10].

From many aspects, the influence of earthquakes on the structure/infrastructure is strongly related to «**SHM** (**S**tructural **H**ealth **M**onitoring)» systems, i.e., '*the implementation of a damage identification strategy to the civil engineering infrastructure*' (Fig. 2). «**Damage**» is defined as '*changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity'* [5], [18], [19]. Damages affect the current or future performance of these systems.

Either from safety or financial point of view, all the civil engineering interventions in the urban environment (especially through the effectuation of great technical works like: airports, dams, plants, ports, railways, roadways, tunnels etc.) are exceptionally demanding in management and maintenance terms [5]. All these certainly stand for the every-day normal life cycle, so obviously the level of demands goes much higher when an earthquake happens.

Figure 1: The disaster's cycle

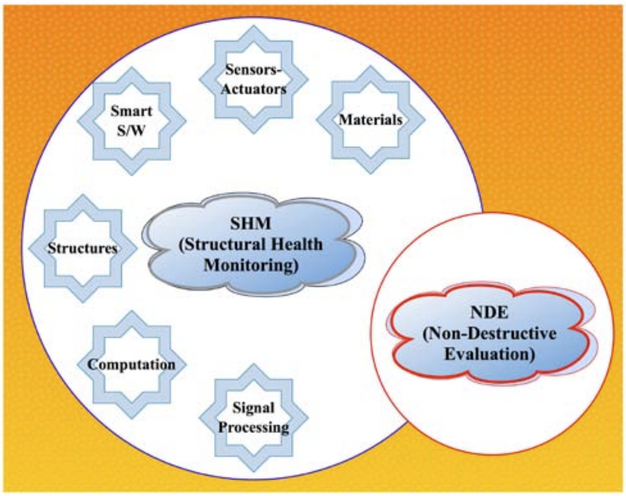

Figure 2: SHM and its components [5]

Concerning civil engineering technical works, there is a really wide assortment of complications and peculiarities (from the need of disassembly of secondary parts to the existence of non-linearities and a variety of uncertainties). All these "special" (sometimes unique for the under inspection structure) characteristics do accumulate questions about safety. The most common damage inspection method, the visual inspection (a.k.a. autopsy), has the disadvantages to be both a labor-intensive and time-consuming one. But safety matters do seek for fast (even better, immediate) answers. Instead of autopsies, another better and 'faster' tool is needed. Such a tool, in addition to speed, has also to ensure and reserve "backwards and forwards" compatibility with the currently inspection and monitoring campaign (methods, data, algorithms) [19].

Such systems, often (with some extensions and modifications) considered as 'integrated decision support systems', by default are based on the use of a database. In such a database, there are multidisciplinary «tastes» and priorities regarding the data (raw field monitored data, attributes, vector/raster etc.) needed to be input. Scientists like geodesists, civil engineers, geophysicists, geologists etc. are among the first who deal with the database´s content. Considering buildings, infrastructure etc., such data could be (in random order): Safety classification of building, valid only for part of the building, damage assessment and vulnerability inspection of buildings, damages (to plaster, to brickwork, to slates, to beams....), knowledge and history data for statistical comparisons, scenarios that predict the impact of a possible disaster event, assessment of the existing Civil Protection/Defence action plans, definitions of failures and weaknesses, real time and on-line input, to name some.

IV. CONTEMPORARY TOOLS, METHODS, SERVICES AND TECHNIQUES

GIS means mainly: position, location, spatial information. Database means ...data (alphanumeric, attributes). So, for such dedicated to earthquake systems, permanent and mobile monitoring units are indispensable, in order to have data. The new era of technological achievements affects vitally everything that relates to real-time geospatial data (regarding their collection, management, processing, analysis, assessment and delivery). An exciting tool that arise from such technology are distributed geosensor networks. They are responsible for an extremely powerful boost to the GIS status and its traditional philosophy of being static and centralized [13]. «**Geosensors**» can be defined as '*any device receiving and measuring environmental stimuli that can be geographically referenced*'. A rough categorization of geosensors could be: (a). Satellite-based providing multi-spectral information about the Earth´s surface. (b). Air-borne sensors for detailed imagery but also for laser scans (LiDAR) of physical or man-made structures. (c). Near, on, or under the Earth´s surface sensors measuring anything from physical characteristics (pressure, temperature, humidity, sound, pollutants) and phenomena (wind, rain, earthquakes), to the tracking of living beings, vehicles etc. [6]. From another relative point of view, such sensors could be: wearable, ambient, remote. A «**geosensor network**» is *'a sensor network that monitors phenomena in geographic space'*. The collection of both temporally and spatially high-resolution, up-to-date data is supported of the "new measurement status", even for broad geographic areas. Such sensors could be mobile or static and furthermore, they are able to passively collect information about the environment or, eventually, to actively influence it. Geographic space can range in scale from the confined environment of a room to the highly complex dynamics of an ecosystem region. Nodes in the network are static or mobile, or attached to mobile objects (e.g. on cars, tracks, buses) or used by humans (e.g. cell phones). A «**Wireless Sensor Network** (**WSN**)» '*consists of spatially distributed autonomous sensors to monitor physical or environmental conditions*'. Such networks cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, enabling also to control the activity of the sensors [1], [16]. Nowadays such networks are used in a wide variety of industrial, engineering and consumer applications (e.g. industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, ocean and coastal monitoring, precision agriculture and fisheries, health-care applications, surveillance and battlefield situations, home automation, traffic control). At this point, it is important to remember that several **N**on-**D**estructive **E**valuation techniques (**NDE**, see Fig. 2) can be converted into SHM techniques, by integrating sensors and actuators inside the monitored structure [4]. Where GPS signals are blocked, indoor positioning [11], [15], [20] system technology can be used to more precisely track locations. After an earthquake strikes the built environment and its residents, retrieving location information is vital for efficient search and rescue operations (known as: **S**earch **A**nd **R**escue (**SAR**), **U**rban **S**earch **A**nd **R**escue (**USAR**)). This location information has to include the information about the neighborhood (e.g. transportation plan of the area, usage types of buildings), buildings within the neighborhood (e.g. layout plans, blueprints and contents of buildings, number of residents) and their residents (e.g. personal and health information) [4].

A remarkable plethora of contemporary disciplines, technologies, services and IT tools are met in this wide field (also with applications to disaster management). To name a few: signals (radio, ultrasound, infrared), RTLS, LBS, RFID, cloud computing, networks (wireless, sensor), sensor-Web, Micro-Electro-Mechanical-Systems (MEMS), Micro-Opto-Electro-Mechanical Systems (MOEMS), Nano-Electro-Mechanical Systems (NEMS), etc. [12], [14], [15], [17], [20]. By taking as given the complete knowledge of each sensor´s capabilities and precision, the default need (and demand) is that all these sensors must be plugged-in into a Web environment. The sensors´ connection to Web, challenges specific needs for them, such as: metadata registration, capability for reporting position, remotely readability, to be controllable (systems, observations, processes) and accessible (parameters).

V. CONCLUDING REMARKS

Quite easily and dynamically, the "traditional" GIS research is getting wider horizons and is «diving» deeper into computer science and its many sub-fields. This fact is coping with a good number of crucial issues like adaptable middleware (i.e., computer software that connects software components or some people and their applications), automated updating of geospatial databases, computer vision, data streaming and processing, location-based services, mobile computing, integration and mining of sensor data, temporal-spatial queries over geosensor networks, virtual reality.

Among the components (phases) of earthquake´s DRMC, Prevention, Preparedness and Response seem to be more 'fertile' for taking full advantage of these new exciting technologies. At this point, it is useful to remember ***The 6 "P"s of Crisis Management***: ***P****roper* ***P****rior* ***P****lanning* ***P****revents* ***P****oor* ***P****erformance*. Certainly, since all these five phases (see Fig. 1) are fundamental for the GIS/Web-GIS structure, decidedly an «advantage-osmosis» for each phase is expected to happen, respectively.

By attempting a simplification based on the target-phases of this paper, the earthquake-disaster could be divided into two stages:

a. Pre-earthquake (Prevention, Preparedness),
b. After-earthquake (Response, SAR, USAR).

For either stage, most of the above mentioned technologic and scientific breakthroughs – related to GIS, Web-GIS – are (or going to be) considerable additions to the 'weapons against the earthquake battle'. Even more, at this high concentration of revolutionary technology around GIS, the geosensors have a leading role. Scientists, researchers and public services, through multi-disciplinary and international efforts, have already presented a large volume of work related to many sub-topics of the field of earthquake risk/disaster management. In order that an optimum exploitation of these resources is achieved, some good planning, strategy and study have to be applied. The scientific results obtained through appropriate experimentations and actual (or simulated) case-studies, will be beneficial for the adoption of newer (or the upgrading of older) specific standards and rules regarding the use of GIS dedicated to earthquake disasters and their management. Obviously, such a new philosophy/methodology will be equally beneficial, for GIS-applications in all kinds of disasters (natural and man-made, as well).

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