DESIGNING WEB-ENABLED SERVICES TO PROVIDE DAMAGE ESTIMATION MAPS CAUSED BY NATURAL HAZARDS

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KEY WORDS: Natural Hazards, Earthquakes, Damage Estimation, Risk Assessment, OGC, SDI, Internet Service

ABSTRACT:

The availability of building stock inventory data and demographic information is an important requirement for risk assessment studies when attempting to predict and estimate losses due to natural hazards such as earthquakes, storms, floods or tsunamis. The better this information is provided, the more accurate are predictions on damage to structures and lifelines and the better can expected impacts on the population be estimated. When a disaster strikes, a map is often one of the first requirements for answering questions related to location, casualties and damage zones caused by the event. Maps of appropriate scale that represent relative and absolute damage distributions may be of great importance for rescuing lives and properties, and for providing relief. However, this type of maps is often difficult to obtain during the first hours or even days after the occurrence of a natural disaster. The Open Geospatial Consortium Web Services (OWS) Specifications enable access to datasets and services using shared, distributed and interoperable environments through web-enabled services. In this paper we propose the use of OWS in view of these advantages as a possible solution for issues related to suitable dataset acquisition for risk assessment studies. The design of web-enabled services was carried out using the municipality of Managua (Nicaragua) and the development of damage and loss estimation maps caused by earthquakes as a first case study. Four organizations located in different places are involved in this proposal and connected through web services, each one with a specific role.

INTRODUCTION

As in most developing countries, seismic hazard and the connected risk play a very important role in Nicaragua and other Central American countries. The geographic context selected for this study is the municipality of Managua (Nicaragua) since it is considered to be representative for many Central American cities as far as seismic activity and vulnerability is concerned. As described by Cowan *et al.* (2002), Managua has been built on a zone rich in geologic faults; over a gap in the volcanic chain, the entire Central American region is surrounded by the tectonic plates of North America, Nazca, Panama, Coco and Caribbean (Marshall, 2007), the Coco and Caribbean tectonic plates acting directly on Nicaragua. All these factors influence the seismic hazard of Managua, Nicaragua and the entire Central American region (Fig. 1).

In recent years the city of Managua has been hit by powerful earthquakes (Table 1) causing many casualties and substantial material damage. The last earthquake in 1972, for instance, left one half of the population homeless (SINAPRED *et al.*, 2005). Due to these reasons, many studies have been conducted in Managua in recent years investigating the seismic hazard, risk and vulnerability of the city (see Section 2.1).

This article presents the design of a set of web services enabling the generation of maps showing an estimation of damages due to seismic events, following the OGC and ISO/TC211 Specifications. The available, usable resources are reviewed: data, programmes, seismic station systems and standardized and interoperable methods that may be offered in the Internet. Some initiatives for automatic assessment of earthquake-related information are also mentioned.

Date	Magnitude (Richter)
Oct. 1885	Unknown
Mar. 1931	5.3 – 5.9
Jan. 1968	4.6
Dec. 1972	6.2

Table 1. Major Earthquakes in Managua between 1885-1972 (Kates *et al.*, 1973)

In recent years, the need to share information in a standardized and interoperable way has been increasingly recognized worldwide. Examples in the geographic information domain are the TIGER data of the US Census Bureau (1990), the Canadian GeoConnections system (1999) and recently the European Directive INSPIRE (Infrastructure for Spatial Information in Europe; 2007) and for data concerning the environment

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(European Commission, 2009). The most recently published news related to the opening up of information reported that the Ordnance Survey, from U.K, will share its data on April 2010 (The Guardian, 2009).

The design of the web geoservices proposed here aims at providing relevant information for government institutions handling emergencies and relief in order to provide disaster preparedness plans, in our particular case for earthquakes. According to Schmitz *et al*. (2006), there is a large number of initiatives promoting the creation of Spatial Data Infrastructures (SDI), however only in a few cases the natural hazard domain is included in them. One of the objectives of this paper is to promote the idea of integrating the natural hazard data within the SDIs.

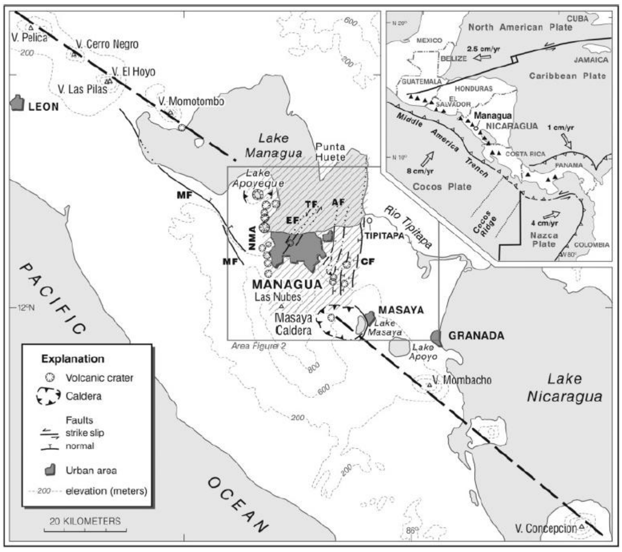

Figure 1. Map showing the major faults (MF, EF, TF, AF, GF) in and around the city of Managua, Nicaragua. The upper right corner shows the map of Central America, the tectonic plates and the volcanic chain (Cowan *et al*., 2002).

The challenge

The challenge of our approach has been the analysis and design of a set of web services complying with the OGC Specifications and ISO Standards, so that by being interconnected as a distributed system, they will use the available resources as promoted by SDI initiatives (reusing information since so much time and resources have been consumed); they will also use the studies about seismic hazards and risks in Nicaragua as well as special programmes in estimation and presentation of damages. Another challenge is the identification of systems and services that ought to be developed to reproduce the Managua experience in other Nicaraguan municipalities (e.g. cataloguing of building typologies) or in other locations where studies with similar resources are being conducted.

The motivation

We propose a distributed and standardized vision in accordance with the OGC Specifications providing data access and information processing for estimation and presentation of the damage caused by natural hazards. Therefore it represents an alternative since at the present time local, time-frozen geographic information copies are used in the form of databases.

Background

In order to carry out this study we examined the concepts behind the current initiatives that aim at a quick and automatic assessment of information associated to seismic events (PAGER, GEM), as well as those allowing public access to hazard and risk data in the Internet (CAPRA). We emphasize that the review has not been comprehensive. Next we describe the above-mentioned cases:

PAGER: *Prompt Assessment of Global Earthquakes for Response* evaluates the number of people, cities and regions exposed to a powerful earthquake (USGS, 2009a); it allows downloading the generated information in several formats, among them a standard GML format; the warning of a seism may be obtained through the Earthquake Notification Services (ENS) after registration has been carried out (USGS, 2009c). ENS also provides information on seisms in several formats, among them XML; from here links are provided to the corresponding PAGER information. PAGER makes some data in GML or KML available even though much of the information it provides is in the form of images. There is no standard way of accessing that information; the user has to browse through the different website links until the desired file is reached. The type of calculation PAGER carries out has very little detail (cities where the seism was felt and number of persons residing). In its website it is indicated (USGS, 2009b) that, in order to estimate building damage or human casualties, it would be necessary to use databases of building inventories. It aspires to centralize this type of information worldwide.

GEM: *Global Earthquake Model* intends to be an independent, consistent standard of worldwide application for calculation of risks, estimate of loss by an earthquake and communication of hazards. Its final aim is to act as a critical tool to support actions leading to a reduction of losses caused by earthquakes (GEM, 2009a). GEM anticipates that the building of the first global functional model of earthquakes will be completed by the end of 2013; they are currently working in the development of a prototype called GEM1 (GEM, 2009b). No published functionality of the prototype has been made available yet. The only technical information shown in the website is a flow chart for hazard processing (GEM, 2009c).

CAPRA: *Central America Probabilistic Risk Analysis* is defined as an information platform to support risk management decision making in natural disasters. From CAPRA's web portal and wiki, documentation, models and programmes about hazards, vulnerability and risks for Central America may be downloaded (CAPRA, 2009a). CAPRA implements OpenGeoNode so as to enable uploading of data and metadata in the GeoNode, to be subsequently published as OGC standardized services (WMS, WFS and CSW; CAPRA 2009b). Standardization is one of the main objectives of the CAPRA methodology. It emphasizes the possibility of uploading data and metadata to a web node (GeoNode) to publish them and support their access through OGC map services. This type of solutions has the disadvantage of the lack of direct connection to the data sources.

On the other hand, the architecture proposed here is distributed, responsibility of data updating in the institutions in charge being maintained; it has the use of geospatial standards in common with the above-mentioned proposals.

RESOURCES FOR LOSS ESTIMATION

To carry out an estimation of damage from natural hazards, several datasets and different calculation methodologies are required, which are usually implemented in different software items. The use of the following resources is proposed: data, methodologies, programmes and results used in the RESIS-II Project in which NORSAR and other Central American institutions participated. The four resource provider institutions were as shown in Table 2.

Agencies	Resources
Managua municipality	Building Stock Inventory.
INETER	Hazard information in GIS format.
INETER	Near-Real-Time earthquake information.
NORSAR	Software for Risk and Loss estimation.
NORSAR/UPM	Software for Risk and Loss representation.
UPM/NORSAR	Software for assigning typology to the buildings
UPM	Geo-Web Services Chaining

Table 2. Agencies and resources involved in this work.

2.1 Studies of seismic risks and vulnerability of Managua

The estimation of damage and loss due to seisms, as with any type of natural phenomena, depends on parameters defined by nature (seismicity and geology), which the vulnerability characteristics of the elements of interest and concern should be added on to. For housing and building in general the major aspects of vulnerability are their composition and structure (Lang *et al.*, 2008). Experiences in the past were the seismic vulnerability of Managua in 2003-2005 and the RESIS-II Project in 2006-2009 (INETER, 2009a).

This paper shows how the appropriate configuration of the computer systems and the available data sources allow us creating a set of OGC Web Services mapping damage estimation from disasters. The implementation of these concepts will allow the integration of new technologies to the study of risks, thus highlighting the multidisciplinary characteristic of this type of activities (Fabbri and Weets, 2005). For this reason the integration of geophysical information in an SDI is being promoted; this favours understanding of the capabilities that may offer the development of this type of technologies to geoscientists (Schmitz *et al*., 2006).

2.2 Model for damage estimation due to seisms

The model to be used is the seismic loss estimation using a logic tree approach SELENA (Molina *et al.*, 2010). It is based on the HAZUS methodology (abbreviation for Hazards United States; FEMA, 2002). It implements an extension of the tree logic for the capacity spectrum methodology (Molina and Lindholm, 2005). This methodology allows calculating the damage on buildings as a function of the available information sources (probabilistic seismic hazard maps, curves modelling the building resistance capacity, models of economic and human losses) and levels of uncertainty associated to input data (Lang *et al.*, 2008).

2.3 Software

SELENA is the acronym used to identify the programme implementing the seismic loss estimation using a logic tree approach model. SELENA has been used in the last seismic vulnerability study and in cities such as Oslo, Naples, Bucharest, Managua, Guatemala and San Salvador among others. It is a tool that provides estimation of building structural damages, and direct economic and human losses relative to physical damage (Lang *et al.*, 2008).

RISe is a tool for processing and transformation of SELENA's input and output data in order to facilitate their integration in widespread map services such as Google; it uses KML as interchange format (Lang and Gutiérrez, 2010).

Earthworm is a system used in INETER since 1996 for management of data flow and the real-time digital storage of data from the seismological stations. Earthworm is used since 2006 as software for seismic monitoring in this institution (Strauch, 2007).

Seisan is a software system interactively used by seismologist to obtain the location and final magnitude of an earthquake. This system also runs a process of publication of the seism in the Internet just a few minutes after the occurrence of the event (Strauch, 1997).

2.4 Data

Database of constructions: Obtained from SISCAT, the municipal cadastre system of Nicaragua. This database contains over 200,000 constructions. Its usefulness in this type of research is based on the information that describes the composition and structure of buildings, the number of inhabitants and the types of use given to the buildings. This information is useful to calculate damages and losses in various circumstances.

SISCAT frames information in four levels according to the capacities of each municipality. This means that not every municipality has the same level of information. 65% of the municipalities have a second level management and they create their cadastral mapping (INIFOM, 2009).

Soil classification: Geographic information layer created from the study of analysis and response spectrum of the soil in different city areas; in the case of Managua, a study carried out by Picado and Parrales (published in 2001) is available. In this case the soil types were classified into four groups in keeping with SELENA's input parameters.

Seismicity database: Historical event database containing epicentre location, date and time, depth and magnitude, provided by INETER in GIS format; it is a historical compilation of the seisms registered in Nicaragua. Part of this information is available online (INETER, 2009b).

Information of the event responsible for the damages; in our case an earthquake will be detected, processed and sent to the seismic station through the Earthworm and Seisan systems.

2.5 Towards interoperability

OGC is the international consortium charged with the definition of open and interoperable standards in the realm of geographic information systems in the Internet. As of November 2009 it was made up of 384 public and private organizations worldwide (Open Geospatial Consortium Inc., 2009a). OGC has been dealing with the interoperability between different spatial datasets since 1994, which was one of its missions since its foundation (Kottman, 1995). However, it is not until the advances of the web as a platform for the OGC Services that this organization described the OGC Web Services (OWS) (Doyle *et al.*, 2001) as geo-processing services that may be connected dynamically and interoperable through the web to create applications. Since then OGC middleware applications have focused on the OWS. The OWS may be grouped in five categories: data, processing, representation, register and applications (Schmitz *et al.*, 2006).

The web geoservice technology for SDI is related to the OGC Specifications.

The interoperability between the above-mentioned resources will be reached through the use of web geoservice technologies according to specifications and standards. This means that every resource will implement the OGC standards that will allow working with interoperability.

3. METHODOLOGY

1) Analysis of the Earthworm and Seisan system architectures of the seismic station to design and implement standardized services of warning and notifications.

2) Study of the algorithms and programmes used in the building typologies with the aim of designing standardized services with these functionalities. Resistance capacity curves are then assigned to every building of the inventory.

3) Study of the software architecture of the SELENA tool and its Application Programming Interface (API) with the aim of publishing their functionalities in a standardized way through a web services interface.

4) Interoperable publishing of the input and output data that is required for the execution of SELENA's geoprocesses.

5) Analysis of the software architecture of the ***RISe*** tool and its API to design standardized services allowing publication of their functionalities in a standardized way.

6) Publication of ***RISe***'s input and output data to facilitate access and visual representation in a standardized way.

7) Data harmonization to be able to apply the same methodology to municipalities other than Managua.

8) Modelling of the sequencing and arrangement of the execution of services published for processing and warning on the basis of the available data.

9) Design of a system architecture connecting all standardized resources through the Internet.

4. RESULTS

The main contribution of our work has been the identification of the OGC/ISO TC211 standards that should be used for each resource involved in the estimation of seismological damage to make them interoperable.

Table 3 relates the resources involved and the necessary standards to ensure the interoperability of the web services proposed in this paper. Figure 2 illustrates the design and connection of those web services as system architecture.

Resources	**OGC standards**	**Relationship name**
Soil classification	WFS, GML, WMS	SC-WFS
Construction inventory database	WFS, GML, WMS	CIDB-WFS
Building typology database	WFS, GML	BTDB-WFS
Assignment of structural vulnerability information to building typologies	WPS, WFS, GML	AV-WPS AV-WFS
Seismicity database	WFS, GML, WMS	SDB-WFS
SELENA	WPS	SELENA-WPS
SELENA input data	WFS, GML	SELIN-WFS
SELENA output data	WFS, GML	SELOUT-WFS
RISe	WPS	RISE-WPS
RISe input data	WFS, GML, KML	RIN-WFS
RISe output data	WFS, GML, KML	ROU-WFS
Earthworm	SAS, WNS	EW-SAS-WNS
Seisan	SAS, WNS	SS-SAS-WNS
Geoservices arrangement (Orchestration engine)	BPEL (not an OGC standard)	OREN-BPEL

Table 3. Used resources and applied OGC Standards

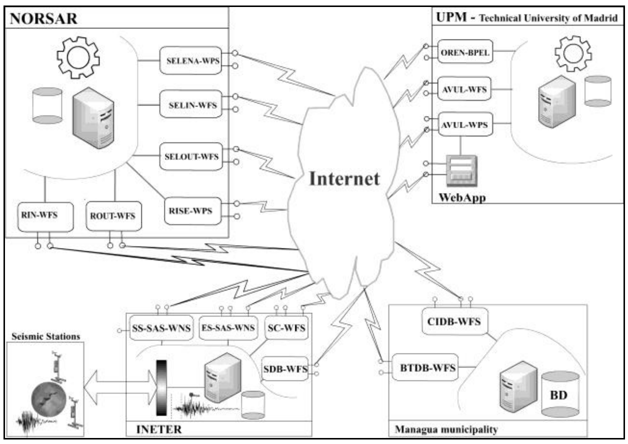

Figure 2. System architecture proposed for the web services

Description of the standards applied to the used resources

The soil classification, the construction inventory database and the seismicity database are published under the WFS Standard (Web Feature Services) that defines the interface of requests, retrieval and editing of geographic features. The published information is sent in the GML (Geographic Mark-up Language) standard format of open information interchange in the form of an XML document. Those same three layers of data are published by means of the WMS Standard (Web Map Service) (Open Geospatial Consortium, Inc., 2009b) that provides visual representation of data in the form of images.

The functionalities of the SELENA and ***RISe*** software tools will be offered to the public through the WPS (Web Processing

Services). Thus the business logic of these programmes gets involved through a standardized API for the web geoservices. OGC conceives WPS as an interface facilitating publication of geospatial processes and it describes the way clients can connect with those processes (Open Geospatial Consortium Inc. 2009b).

The input and output data of SELENA and *RISe* are sent by means of the GML standard format. The inputs may come from the WFS that provide querying of the data sources. In particular, *RISe* could publish the data in KML format, allowing visualization of those data over other geographic data sources of mass markets such as Google Earth, Bing, Yahoo, etc.

Next we describe two resources providing derived information.

The first resource is a view of the cadastral database that will contain the different construction typologies. This view will be offered as a derived data source through WFS. The result of querying this service will be a dataset containing the following information: typology of wall and roof construction, type of utilization (occupancy) assigned and year of construction.

The second resource consists of an assisted process where an operator relates each one of the typologies to pre-established categories. This is a manual process because the terminology used in each region to describe the building materials and the types of usage may be – actually is – different. As a first approach to provide this assisted process with interoperability, the use of a WPS type processing service is proposed that will be supported by a web user interface. The result of this process will be the same initial set of dataset to which another attribute has been added indicating the seismic capacity curve of the building. This information will be used together with the spatial information associated to the building by the SELENA geoservice.

With our architecture we propose the use of the standards related to the Sensor Web Enablement for notification and warning of the movements detected by the seismic station through the Earthworm and Seisan systems. The warnings or notifications generated by these standardized services represent the triggering mechanism of the damage estimation processes.

The arrangement of the above-mentioned geoservices will be modelled and stored in BPEL (Business Process Execution Language for Web Services). BPEL is a standard to define process execution, their rules and conditions or their recursivity (Juric, 2006). There are several execution engines of the logic stored in BPEL: ActiveBPEL, IBM BPEL4J and Oracle BPEL Process Manager.

Next figure shows the relationships between the different geoservices of the proposed architecture.

5. CONCLUSIONS AND FUTURE WORK

The main contribution of our work has been the standard geoservice architecture to generate damage estimation maps from seismic events. For the design of these services we have tried to reuse to the utmost the resources used for the current methodologies: SELENA, *RISe*, cadastral database and Earthworm.

The application of standardized technologies to interconnect autonomous systems ensures their interoperability. This architecture is conceived to be capable of being used in different geographic domains and it could also be applied in different natural hazard scenarios.

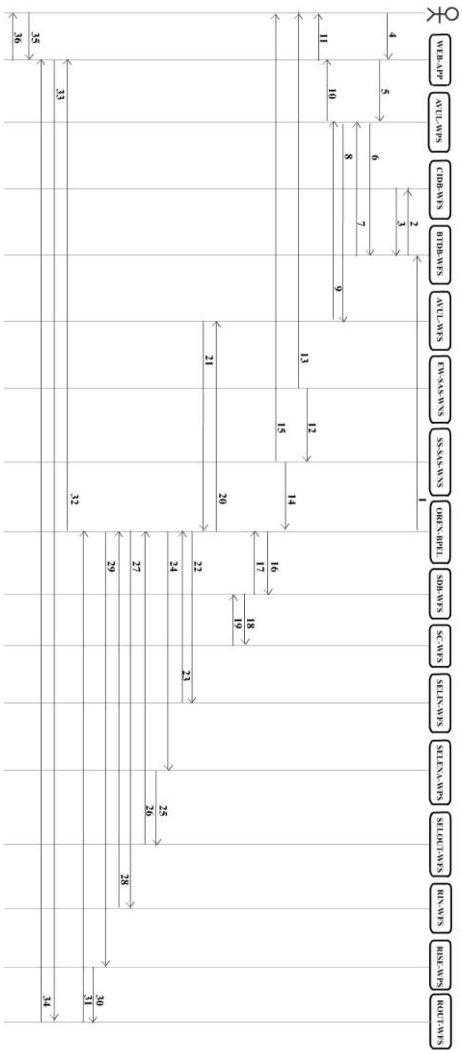

Figure 3. Sequential diagram of the proposed architecture

Other remarkable characteristic of the proposed architecture is that it keeps the roles of actors and people in charge of the different information sources used in the calculations. Likewise this also occurs in the case of the algorithms embedded in the geoprocesses. The municipalities keep the cadastral data and the seismic stations channel the events.

An issue that will require a coordination effort is data model specification to be offered by the municipalities with the cadastral data. The same applies to adaptation to the standards that are being developed in the geological context, e.g. the GeoSciML (Geoscience Mark-up Language), defined for geological data (OneGeology, 2009). This way it will be possible that the geoprocesses could exploit the data in a transparent manner.

Finally, as a future proposal we suggest graphic publishing as maps of the seismic events – or events of another type – through geo-referenced syndicated news (GeoRSS).

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