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# Decision Making in the Context of Natural Disasters Based on a Geographic Information System and the Internet of Things (IoT)

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## Abstract

Decisions within the company, managers in countries or regions are made by one or more groups of decision-makers. The management of natural disasters involves several specialized decision-makers (experts, firefighters, police officers, drivers,). The aim of the chapter is to improve decision making in the context of natural disasters situation. Zero risk in the world does not exist due to natural phenomena that occur randomly and appear suddenly. It is essential to manage the risks in the situation of natural disasters and also to confront the influence of natural disasters on the phenomenon of Soil-Structure Interaction. For this, this chapter presents a conceptual architecture of a knowledge base to manage the risks of natural disasters remotely by a Geographic Information system (GIS) and embedded systems. This architecture is based on the integration of data via different sources of information (GIS, satellites, electronic sensors and comments from experts). To properly manage this information, this chapter uses the ontology of Soil-Structure Interaction With Agents External (OSSIWAE) in the context of the Internet of Things (IoT). A case study is conducted on a prototype of a model for building a structure three-story for testing the usability of the proposed architecture.

**Keywords:** Risks of natural disasters, Soil-Structure Interaction; Geographic Information system, Ontologies, Internet of Things (IoT)

## 1. Introduction

Natural disasters (Flood, Storm, Earthquake, Extreme temperature, Landslide, wind...) are phenomena that occur every time and humans must find appropriate solutions to minimize the damage. With the increase in the use of embedded system and the web technologies in all fields. These technologies have enabled us to help find solutions that were not possible previously or it is difficult to access a certain types of disasters by decision makers. The aim of the chapter is to improve decision making in the context of natural disasters. Zero risk in the world does not exist due to natural phenomena that occur randomly and appear suddenly. It is essential to manage the risks of natural disasters and to inform the people concerned, the leaders, the citizens, firefighters, police officers, drivers... etc. However, the

phenomenon of Soil-Structure Interaction poses real and important problems for the design of new structures that resist to natural disasters because of the heterogeneous mechanical behavior of the soil, which changes through the influence of external agents such as: temperature, water, rain snow (freeze–thaw phenomenon) earthquake (dynamic effect). For this purpose, this chapter presents a conceptual architecture of a knowledge base to manage the risks of natural disasters. The architecture of the system is based on the use of ontology, a Geographic Information system (GIS), a sensors electronic system and the documents of experts in the context of Internet of Things (IoT) in order to build a knowledge base on the influence of external agents on the phenomenon of Soil-Structure Interaction. In this chapter an ontology of Soil-Structure Interaction With Agents External (OSSIWAE) was proposed to capitalize the information on agents external in a real time in order to fully understand, analyze and estimate this phenomenon. The proposed ontology was validated by experts in civil engineering, who helped us to build this ontology. In order to validate the proposed architecture, a web application is developed that supports this architecture. The rest of this chapter is organized as follows. First the related works on the Geographic Information System and the ontologies for the management of natural disasters are detailed in Section 2. In Section 3, the ontology for representing the phenomenon of Soil-Structure Interaction with the connection of natural disasters (OSSIWAE) is presented. In Section 4, the architecture of a knowledge base of natural disasters is presented. Finally, the chapter ends with the implementation of a web platform applied on the prototype of a model for building a structure three-story in the context of Internet of Things (IoT) for testing the usability of the proposed architecture.

## **2. Related work**

This section describes the proposed related work that used the Geographic Information System and the ontologies for the management of natural disasters.

### **2.1 Geographic information system for the management of natural disasters**

[1, 2] Geographic Information Science is developed to manage and analyze spatial data, which is based on geomatics technologies, Geographic Information Science as a technology/system allows the storage of spatial information in the relational database. According to [3] Geographic information system (GIS) has emerged as a dominant tool for accumulating, analyzing and displaying spatial data and using this data for decision making in several areas. In addition to [3] Geographic Information System (GIS) is one the technologies that evolves to allow people to solve many geographic problem quickly, effectively and easily with the abilities to make analysis, especially location analysis in combination with traditional database systems.

There are several computer systems that manipulate geographic databases such as ArcGis, QGIS, MapInfo, SuperGis, Surfer...etc. and at the same time there are GIS web applications to make GIS accessible through web technologies.

Several works have shown the interest of GIS for the study of floods and risks. In [4], authors proposed a methodology by using the SAR data along with GIS for flood water mapping, monitoring and analyzing the propagation of flood water in a flood prone area. In [5], authors proposed an approach based on GIS for flood management strategy in a river basin; this approach consists of two main interlinked components the first is a proper flood management strategy, and the second is the determination of the flood-hazard areas. This work [6] demonstrated the importance of the use of earth observation (EO) products and geographic information

systems (GIS) in disaster-risk management. [7] used the data collection methods and GIS applications to develop a detailed mapping of the main natural and human factors responsible for the flooding phenomenon. [8] used remote sensing and GIS to reduce flood damage in the study area by improving flood forecasting and flood defense. In [9], authors developed a flood sensitivity spatial decision support system (SDSS) that integrates the spatial analytical strengths of a GIS platform with the structured analytical hierarchy process (AHP).

This section demonstrates the importance of using a GIS for flood risk management, however, but few works that integrate embedded sensors and the semantic web with a GIS to effectively manage natural disasters.

## **2.2 The ontologies for the management of natural disasters**

An ontology can be defined as an explicit specification of a conceptualization [10]. In recent years ontologies have been used in various fields of application to create knowledge bases (search engines, e-commerce, electronic library, etc.). Applications not only need to exchange data and information with each other but also need to agree on the semantics of that data and information. Knowledge can describe and explain its meaning using the following elements (class, instance, attribute, relation, etc.). The organization of these elements of description of knowledge can be done in the form of ontology. So an ontology is the set of individual instances of classes, specifying the specific values of the attributes as well as the restrictions on the attributes to constitute a knowledge base. According to Noy [11] there is not just one correct way to model a knowledge domain there are always varying alternatives, the best solution generally depends on the application carried out and the anticipated developments. In the context of the creation of ontologies in the field of soil science, in the field of structure and the field of disaster risk management, we mention: In [12], authors proposed an Ontology-Based Knowledge Network of soil/water physicochemical & biological properties (soil/water concepts) for the semantic representation of infiltration/percolation process of contamination water through soil structure and porous media. According to [13] Pile foundation is a basic form that can adapt to complex geological conditions and is widely used in high-rise buildings, bridges, ports, and other important structures, this work proposed an integrated evaluation system that can make reasonable evaluations of pile integrity where specific measured reflective wave curves. The evaluation system based on the ontology of pile integrity evaluation (OntoPIE), this ontology used for quantitative identification of pile defects and qualitative evaluation of pile integrity. THE OntoPIE represent the essential terms of the pile integrity evaluation system which includes the degree, length, depth, and integrity category of the pile defects. In [14], authors proposed an ontology of soil properties and processes for representing soil properties, processing and their interaction in order to make integrated decisions, and to combine the knowledge and expertise in multiple areas, such as roads, soil, buried assets, sensing, etc. [15, 16] proposed an ontology-based simulation environment in agriculture and natural resources for constructing models and representing equations and symbols in a formal ontology language, the utility of the approach by building moderately complex models of soil–water and nutrient management. This approach has the advantage of making models more explicit and better defining the meaning of symbols used in a model. [17] Proposed ontology of the flood domain and describes how they can be benefited to access, analyze, and visualize flood-related data with natural language queries. Flood ontology developed under three major ontological branches (i.e. Natural Hazard, Instrument, and Environmental Phenomena) Geological Hazards (e.g. earthquake), Meteorological Hazards (e.g. tornado), Diseases, Wildfires, and Floods. Flood ontology utilized in



cyberinfrastructure systems for natural hazard preparedness, monitoring, response, and recovery. And to allow visual, intuitive, and collaborative development for domain experts who may have a limited technical background [18]. Aims to use the data from different sources to reason on them. Data comes from water sensors, satellite images, field studies, hydrological models, GIS, etc. to model risk management for flash floods. [19] proposed integrated watershed flood risk assessment ontology based on different perceptual models of watershed flood risk. This ontology represents the complex process involving physical systems and organizational systems in flood risk assessment [20]. Proposed the ontology named FloodOntology for floods forecasting based on continuous measurements of water parameters gathered in the watersheds and in the sewers and simulation models. FloodOntology is used for obtaining a structured and unified knowledge-base on the flooding risk forecasting. Three main domains are used hydrological, hydraulic and sensor networks. In [21], the authors identify the core literature available on flood ontologies and present a review on these ontologies from various perspectives [22]. Proposed the Ontology for River Flow and Flood Mitigation (ORFFM) for semantic knowledge formalization with semantic understandability of irrigation, disaster management, related administrative and agricultural domain concepts. This ontology allows the effective coordination, collaborative response activities leads to reduce the impact of a disaster and improve information representation among stakeholders.

The phenomenon of Soil-Structure Interaction poses real and important problems for the design of structures in order to resist to the natural disasters due to heterogeneous mechanical behavior of soil which changes through the influence of external agents such as: temperature, water, rain snow (freeze–thaw phenomenon) earthquake (dynamic effect). However the cited works are not considered this knowledge in ontology. For this purpose, we based on the existing ontologies and the Soil-Structure Interaction model proposed in literature in order to propose a new ontology to represent the phenomenon of Soil-Structure Interaction with the connection of external agents named OSSIWAE.

### **3. Ontology of soil-structure interaction with external agents proposed**

In this chapter, the Protégé tool 5.2 is used to realize the ontology of OSSIWAE. There are several methods for developing ontology. To design this ontology, the iterative method for the development of the ontology, proposed by [11] is followed.

The development of the ontology is started by defining its domain and scope by answering the following questions:

What is the field that ontology will cover? The domain of the ontology is the concepts used in the domain of Soil-Structure Interaction and natural disasters, this ontology conceptualizes the concepts in different domain Soil, Natural Disasters, Structures and the relations between them. The relations which represent the interactions between Soil, natural disasters and structures are taken into consideration with sensors. The ontology therefore includes all the concepts of the external agents which influence on the structures such as the temperature, water, rain snow (phenomenon of freeze–thaw) the earthquake (the dynamic effect) ... etc. And describe the concepts which link heterogeneous soil and structure information.

What are the development goals of ontology? The ontology is designed with the aim of formalizing and clarifying the semantics of the collection of information by electronic sensors. This formalization allows us to implement the semantics of information in Web tool dedicated to the actors involved in the decision process. And also to ensure the semantic integration of data via different sources of information (GIS, satellites, electronic sensors and comments of experts).

Reuse of existing ontologies:

The objective of this step is to reuse existing ontologies even if they have a different objective from ours. We can reuse all or part of these ontologies after having adapted them to our needs. Some concepts proposed by [12–14, 17] are reused.

Identification and structuring of ontology concepts:

To identify the main concepts of ontology, the concepts proposed by [12–14, 17] are extracted and enriched them with the concepts analyzed in the Soil-Structure Interaction model proposed in literature and the concepts proposed by civil engineering experts. These concepts are organized and structured in an ontology called “OSSIWAE”. Finally, the Protégé editor is used to define this ontology (**Figure 1**).

This ontology has been validated by experts in civil engineering who have helped us to build and enrich the concepts of ontology.

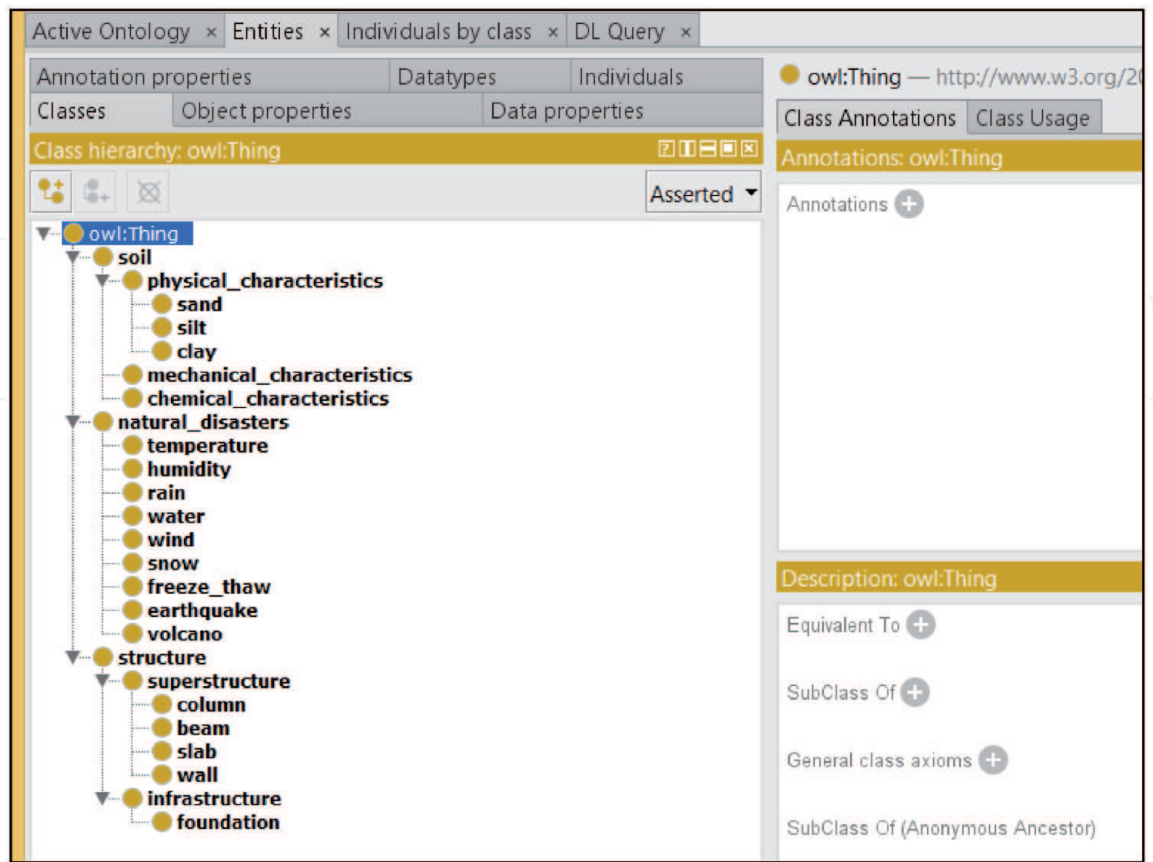
We explain below some of the concepts identified in this ontology.

The top-level classes of the OSSIWAE ontology are Soil, natural disasters, structures (superstructure and infrastructure) and we have hierarchized each class with its subclass.

The class Soil its subclass are physical characteristics, mechanical characteristics and chemical characteristics. For example the class of physical characteristics its subclass are sand, silt and clay.

The class structures its subclass are superstructure and infrastructure, the class superstructure its subclass are column, beam, slab and wall, the infrastructure is foundation.

The class natural disasters its subclass are temperature, Humidity, Rain, water, Wind, snow, freeze–thaw (freeze–thaw phenomenon) earthquake (dynamic effect), volcano. And each class has the values for example the concept of Humidity (has value), Temperature (has value), Wind (has frequency and has direction).



**Figure 1.**  
The OSSIWAE ontology.

The impedance in Soil-Structure Interaction is the most important parameter, which represents the interaction between the structure and the soil, for this, this parameter is represented by relations in order to clarify the knowledge in ontology. Then these relationships used to capture useful information by sensors installed in different places in the soil and the structure. We have used the following four relationships for linking between the classes of ontology: soil liquefaction, Structural vibration, soil compaction and Structure dilatation.

4. Proposed architecture of a knowledge base of natural disasters

The proposed architecture is illustrated in Figure 2. The conceptual architecture is made up of four parts:

The first part is the Information gathering; this part uses GIS to map areas and so uses electronic sensors to collect information. It uses a set of sensors installed in

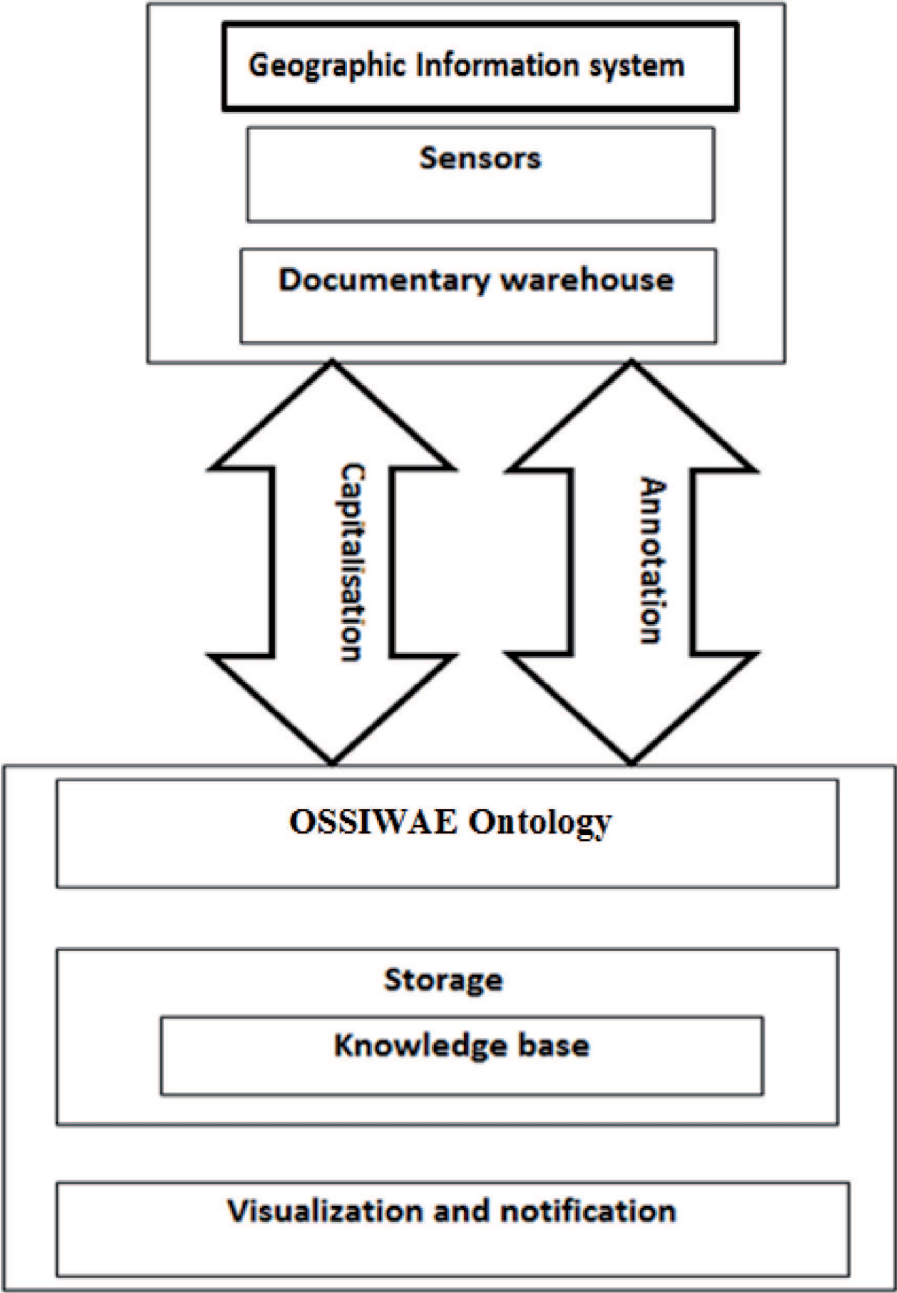


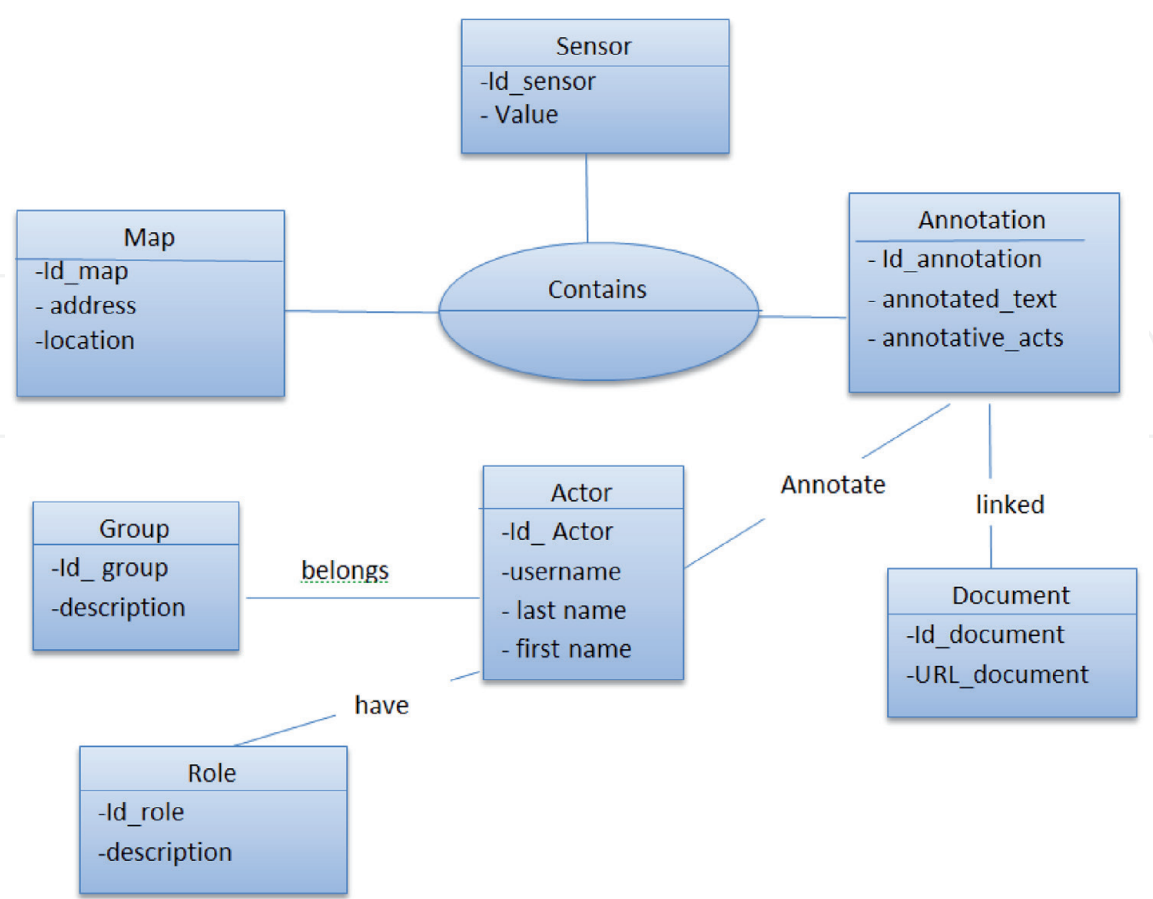
Figure 2.  
Architecture of a knowledge base of natural disasters.

well-defined places in the structure and in the Soil. These sensors can communicate with each other. The collection of information also uses a documentary warehouse for the collection of documents (expert report, opinions, etc.). These documents are annotated by the ontology in order to extract additional information. Documentary warehouse allows experts to record the events produced in order to make the right decisions. In the previous work [23, 24] we have demonstrated the importance of annotating documents handled during the process of decision making.

The second part is the knowledge base, it is used to store the information sent automatically by the electronic sensors (high water level, vibration, temperature, humidity, rotation, acceleration, inclination, force, etc.) and linked this information to graphical information mapped by GIS and information annotated by experts. **Figure 3** gives the class diagram of the knowledge base. The validation phase for the classification of knowledge according to the criteria of value and veracity of knowledge for the group is important. According to [25] there are three categories of knowledge among the knowledge to be certified (validated, not validated and rejected), we used these three categories as annotative acts between the actors of the group to certify and validate their knowledge and the data collected. In this function the following annotative acts are used: a validated annotation, a rejected annotation and an invalidated annotation.

The third part is the OSSIWAE ontology. The ontology used to conceptualize the interaction between structure and soil. The ontology is used to semantically capture the information sent by the sensors and also to annotate the documents stored in the document repository. The OSSIWAE ontology described in Section 3.1.

The fourth part is the user interface, which allows users to view the evolution in real time of the graphs for each mapped area and send them the Short Message (SMS) of notifications to mobile phones for decision makers to inform themselves



**Figure 3.**  
The class diagram of the knowledge base.



and take the necessary measures. And also allows fully understanding, analyzing and estimating this phenomenon by experts.

5. Implementation

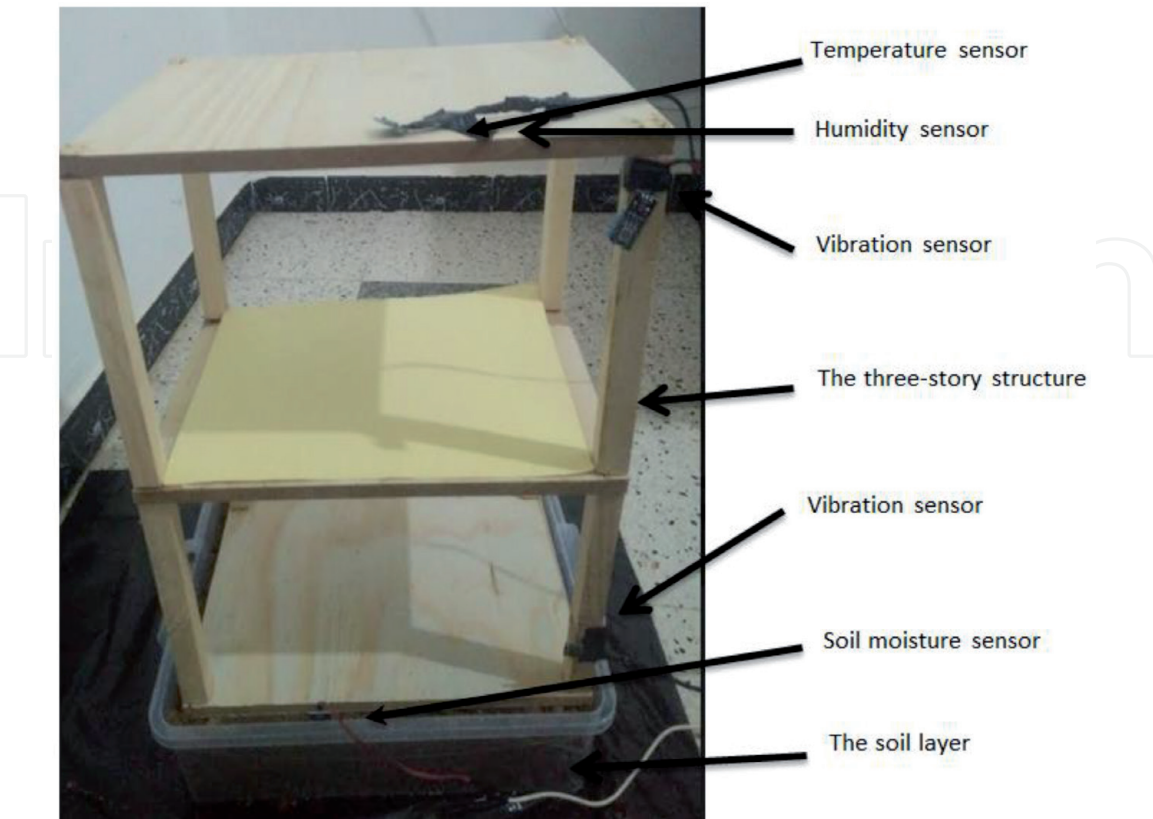
The main technologies used to develop this application are: jQuery it is a JavaScript library is used to facilitate the development of user interface. PHP language it is used for manipulation of data in the data base. Asynchronous JavaScript and XML (AJAX) is used to send data to server. MySQL server it is used for the creation of the database to store the information.

For the Geographic Information system (GIS) a web cartographic server was developed which allows for managing maps and data. This server makes it possible to share data and to link with the data via sensors and annotations. The HTML canvas element it is used to draw graphics, with using the JavaScript to add annotation, draw a line, draw a circle, draw a Text... on cards.

For the electronics system, the Arduino nano and uno with the different sensors used to capture the data in real time. The programming software of the Arduino board is used, which serves as a code editor in a language close to C to program this part.

For document annotation, an annotator was developed to annotate word and excel documents via ontology. These annotations are linked with the areas mapped by the GIS and the information collected by the sensors.

A model for building a structure three-story was prepared and then put on the soil. Vibrations are applied to simulate data collection via sensors (**Figure 4**) then these data are processed and display it in a web page to link with the relevant geographic map.



**Figure 4.**  
*Model of soil-structures interaction with sensors.*

6. Conclusion

The risk management of natural disasters becomes a necessity to take the necessary measures at the right time and in the right place and for the construction of new structures weak and resistant to natural disasters. This chapter presents a conceptual architecture based on ontology, embedded systems and Geographic Information system for the creation of a knowledge base on the phenomenon of soil-structures interaction with the connections of external agents in real time in order to fully understand, analyze and estimate this phenomenon by experts. Considering that the ontologies play a critical role to solve the problem of the heterogeneity of external and multi-source information. An Ontology of Soil-Structure Interaction With Agents External (OSSIWAE) was proposed for managing and integrating the data coming from different sources of information (GIS, satellites, electronic sensors and comments from experts). To validate this architecture, a web platform was developed in the context of Internet of Things (IoT), which supports the different technologies used. Then, a case study is conducted on a prototype of a model for building a structure three-story to simulate data collection. Given the large number of mapping areas, in this chapter some sensors are installed. As a perspective we want to increase the number of sensors to capture other parameters.

List of acronyms and abbreviations

IoT	Internet of Things
GIS	Geographic Information system
OSSIWAE	Ontology of Soil-Structure Interaction With Agents External
SAR	Synthetic Aperture Radar
EO	Earth Observation
SDSS	Spatial Decision Support System
AHP	Analytical Hierarchy Process
ORFFM	Ontology for River Flow and Flood Mitigation
AJAX	Asynchronous JavaScript and XML
HTML	HyperText Markup Language
SMS	Short Message Service

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