PhD Program in *Ciencia y Tecnología Informática*

PHD THESIS

SEMA4A: A KNOWLEDGE BASE FOR ACCESSIBLE EVACUATION AND ALERT NOTIFICATIONS IN EMERGENCIES

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DEPARTAMENTO DE INFORMÁTICA
Leganés, October 2013

TESIS DOCTORAL(PHD THESIS)

SEMA4A: A Knowledge Base for Accessible Evacuation and Alert Notifications in Emergencies

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Título (Degree): Doctorado en Ciencia y Tecnología Informḿica
Calificación (Grade): ____________________

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Abstract

When an emergency occurs or is going to occur, the aim of organizations and agencies involved in the response phase is to restore quickly a safe situation and reduce the number of victims and damages.

The notification of information about the kind of emergency, its characteristics, the location of safe places and available procedures for reaching them has a crucial role in order to facilitate the evacuation of citizens. Several organizations and agencies have been promoting the development of Information Technology (IT) tools, called Emergency Response Information Systems (ERIS) for the management of the activities performed in response to the emergencies. In particular, these systems provide modules for collecting, updating and notifying information about imminent disasters to potential affected people. Such notifications can be communicated through different channels, like websites, emails, text or voice messages.

But to effectively inform people about an emergency, the notifications should be adapted automatically to each user's profile (e.g. functional or contextual disabilities, elderly, children), the kind of emergency (e.g. typhoon, earthquake, tornado), the communication channel (e.g. PDAs, smartphones, pagers) and any other exceptional circumstances (e.g. interrupted roads, collapsed exit, dangerous area). For example, when a fire occurs in a building, a blind person should be alerted by audio signals or text messages (assuming she has a text-to-speech software on her device). Moreover, information can guide her to an assistant that can help her in reaching the exit.

The efficacy of emergency notifications depends also on how different Emergency Notification Systems (ENS) communicate and interoperate with each other in order to share information even with different terminologies and types of disasters. For avoiding semantic incompatibilities, a common language is needed to improve

the coordination not only among systems, but also among users. In fact, codifying the semantics of shared information in an accessible way could help citizens in interpreting notifications without misunderstandings and emergency operators in communicating among them.

Modelling knowledge on alerting and evacuation processes, using expert systems, neural networks or ontologies, can help in personalizing emergency notifications and evacuation procedures. In particular, we posit that the knowledge base required for the personalization mechanism should cover at least four domains: accessibility, technology, emergency and evacuation procedures. These domains cover the factors to take into account for adapting the notifications. Consequently, the accessibility is considered a representation for the user's profile, technology for the interactive devices and the communication channel, emergency for the characteristics of the situation and evacuation procedures for the escaping measures.

In this thesis, we propose the design of an ontology called SEMA4A (Simple Emergency Alerts 4 [for] All). The ontology is a knowledge representation based on semantic rules that allows to model articulated knowledge through the definition of complex relations among concepts from different domains. This choice is also related to the possibility of using specific tools based on first order logic for verifying the validity and the integrity of the proposed representation.

The development of the ontology has to meet the objectives that motivated this research work: consistency, completeness, understandability and interoperability with existent systems and protocols. For the consistency, we have run a reasoner tool called Pellet obtaining that there are not redundancies and the mapping is syntactically coherent.

Concerning completeness and understandability, we have performed a quantitative and a qualitative evaluation. The goal of the quantitative evaluation is to compute three well-known functions in the domain of ontological engineering: precision, coverage and accuracy. These three measures evaluate how much the ontology is representative respect to the domains of interest (i.e. accessibility, emergency, evacuation and technology). In the qualitative evaluation, we have involved international experts in accessibility, evacuation and emergency to test the validity of the proposed mapping with respect to their expertise.

Finally, the interoperability has been guaranteed codifying SEMA4A with a standard language called OWL (Ontology Web Language) and following formal recommendations published as an initiative of the W3C (World Wide Web Consortium).

Taking into account the results obtained from the evaluations, we posit that the proposed ontology addresses needed information for sharing and integrating alert notifications about emergencies and evacuation procedures into existent solutions (i.e. notification mechanisms, information systems, communication protocols). As proof of this, we have developed three use cases in collaboration with the DEI Group of the University Carlos III of Madrid. SEMA4A has been applied for adapting available information considering several factors: the user's profile, the kind of emergency, the communication channel and other exceptional circumstances. The first use case, called CAPONES, sends emergency alerts adapting the content and the visualization to the needs of involved users. The second system is NERES which aims at generating and notifying personalized evacuation routes. The last case is the EmergenSYS platform that provides three different mobile tools for sending alerts in two directions: from citizens to emergency operators and from emergency operators to citizens.

Resumen

Durante una emergencia, el objetivo de las organizaciones y agencias involucradas es de responder a la misma para restaurar rápidamente una situación segura y reducir el número de las víctimas y los daños.

En este ámbito es fundamental enviar a los ciudadanos afectados notificaciones sobre la emergencia especificando el tipo, las características, la ubicación de los lugares seguros y cómo llegar a ellos. De esta forma se pueden facilitar el desalojo y la evacuación de la área peligrosa. Varias organizaciones y agencias han estado colaborando en el desarrollo de los Sistemas Informativos para la Gestión de Emergencias (SIGEs). Estos sistemas proporcionan deferentes servicios basados en las Tecnologías de la Información y la Comunicación (TIC). Uno de ellos es la gestión de la información relacionada con la situación y su consecuente notificación a los ciudadanos a través de diferentes canales, como por ejemplo sitios web, correos electrónicos, mensajes de voz y texto.

Para que las notificaciones sean efectivas, es necesario proporcionar un mecanismo de personalización que adapte automáticamente la información a enviar teniendo en cuenta el perfil de cada usuario (por ejemplo, discapacidades funcionales o contextuales, ancianos y niños), el tipo de emergencia (por ejemplo, incendios, terremotos y tornados), el canal de comunicación (por ejemplo dispositivos móviles, dispositivos inteligentes y correo electrónicos) y cualquier otra circunstancia que se pueda considerar relevante (por ejemplo, carreteras cortadas o colapsadas y zonas peligrosas). Por ejemplo, cuando se produce un incendio en un edificio, una persona invidente puede ser alertada por una señal audio o un mensaje de texto si tiene instalado en su teléfono un convertidor de texto a voz. No solo el tipo de alerta, si no también el contenido de la misma tiene que adaptarse. En el caso del invidente, la información recibida le guiará hacia un asistente que le pueda ayudar

a llegar a la salida.

La eficacia de las notificaciones de emergencia depende también de cómo los diferentes SIGEs comunican y colaboran entre sí con el fin de compartir información. En este caso, hay que tener en cuenta que cada sistema podría utilizar una terminología diferente. Para evitar cualquier incompatibilidad semántica, se necesita un lenguaje común con el objetivo de mejorar la comunicación no sólo entre los SIGEs, sino también hacia los usuarios. De esta forma, se evitarían posibles malentendidos en la interpretación de la información recibida por parte de los ciudadanos y compartida entre los operadores de emergencia.

Una posible solución a esta necesidad consiste en modelar el conocimiento sobre las alertas de emergencias y los procesos de evacuación desarrollando un sistema basado en la inteligencia artificial, como por ejemplo sistemas expertos, redes neuronales u ontologías. En particular, se considera que el conocimiento a modelar necesario para definir el mecanismo de personalización debería cubrir por lo menos lo siguientes cuatros dominios: accesibilidad , tecnología, emergencia y evacuación. Cada uno de estos dominios representa un factor especifico de la personalización. La accesibilidad se refiere a las características definidas en el perfil del usuario. La tecnología contiene los tipos de dispositivos y el canal utilizados para recibir información. La emergencia representa todo lo que se conoce sobre la situación critica mientras la evacuación incluye los procedimientos y las medidas a tomar para evacuar.

En esta tesis, se propone el diseño de una ontología llamada SEMA4A (Simple Emergency Alerts 4 [for] All, Alertas de Emergencias Simples para Todos). La ontología es una representación de una área de conocimiento basada en la definición de reglas semánticas. A través de estas reglas, es posible definir modelos complejos que relacionen conceptos provenientes de diferentes dominios. Además, el uso de ontologías nos permite aplicar una serie de herramientas basadas en la lógica del primer orden para verificar la validez y la integridad de la representación resultante.

El diseño de la ontología tiene que cumplir con los objetivos que han motivado este trabajo: la coherencia, la integridad, la comprensión y la interoperabilidad con los sistemas y los protocolos existentes. Cada una de estas propiedades ha sido evaluada utilizando técnicas especificas. Para la coherencia, se ha utilizado un razonador llamado Pellet. El resultado obtenido confirma que la definición de los conceptos y de las relaciones incluidas en SEMA4A ses semanticamente coherente.

En cuanto a la integridad y la comprensión, hemos realizado dos tipos de evaluación: una cuantitativa y otra cualitativa. El objetivo de la evaluación cuantitativa es calcular tres funciones ya conocidas en el campo de la ingeniería ontológica: cover, accuracy y precision. Estas funciones nos permiten medir cuanto la ontología es representativa para los dominios de interés. En el ámbito de la evaluación cualitativa, hemos involucrado a expertos internacionales en materia de accesibilidad, evacuación y emergencia para qué opinen sobre SEMA4A y su valor respecto a la experiencia propia de cada uno.

Por último, se ha cumplido con la interoperabilidad implementando SEMA4A con un lenguaje estándar llamado OWL (Ontology Web Language, Lenguaje Web para Ontologías) y siguiendo las lineas guías publicadas como iniciativa de la W3C (World Wide Web Consortium).

Teniendo en cuenta los resultados obtenidos al finalizar las evaluaciones, finalmente podemos afirmar que la ontología propuesta en esta tesis puede ser utilizada por otros SIGEs para personalizar y compartir la información disponible sobre situaciones de emergencia y procedimientos de evacuación. Como prueba de ello, hemos desarrollado tres casos de uso en colaboración con el Grupo de DEI de la Universidad Carlos III de Madrid. SEMA4A se ha aplicado como parte del mecanismo de adaptación de la información disponible teniendo en cuenta el perfil del usuario, el tipo de emergencia, el canal de comunicación y otras circunstancias excepcionales. El primer caso de uso, llamado CAPONES, envía alertas de emergencia personalizando el contenido y la visualización del mensaje (texto, imágenes o realidad aumentada) para mejor cumplir con las necesidades de los usuarios involucrados. El segundo sistema es NERES cuyo objetivo es adaptar y notificar las rutas de evacuación respecto al plano de emergencia oficial. El último caso es la plataforma EmergenSYS que ofrece tres aplicaciones móviles diferentes. La primera permite a los ciudadanos de notificar incidentes al centro de operaciones en calidad de testigos o victimas. La segunda es un botón de pánico que el ciudadano puede presionar para que automáticamente llegue una notificación al centro de operaciones. La tercera permite a los ciudadanos recibir información útil acerca de una emergencia cercana, incluyendo también la ruta de evacuación personalizada.

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Chapter 1

Introduction

When an emergency occurs or is going to occur, the aim of organizations and agencies in charge of managing crisis is to organize the activities for restoring quickly a safe situation and reduce the number of victims and damages. These activities aim to prevent, prepare, respond and mitigate such kind of events as part of the emergency management process (Waugh and Streib, 2006).

As pointed out by Turoff in (Turoff, 2002), a crucial activity for the emergency management process consists in establishing a bidirectional communication channel between citizens and emergency operators. Through this channel, it would be possible to share updated information about the current situation. On the one hand, the citizens receive alert notifications about the kind of emergency, its characteristics, the location of safe places and available procedures for reaching them if an evacuation is needed. On the other hand, the operators take advantage of receiving information from who is directly involved in the emergency as witness or victim. In this way, the citizens can participate actively at the response phase collaborating with the operators for reaching an effective solution.

When a fire occurs in a building, the operation centre in charge of managing the event identifies the dangerous areas and requires their evacuation. To make more effective the evacuation, first of all the available routes have to be updated considering any damages due to the fire (e.g. interrupted corridors). Secondly, the citizens have to be alerted with general information about the situation and the specific instructions to follow for reaching a safe place. To do this, the operation centre has to guarantee that each user can access and understand the content of the notifications. For example, a person with a visual impairment can receive a text message only if she has a text-to-speech tool. Not only the abilities of the users but also the context could affect the effectiveness of the notified alert. If there is smoke in the environment, a route visualized in a map could be difficult to navigate.

Generalizing this idea, to effectively inform people about an emergency, the notifications should be adapted considering the users' profile (e.g. functional or contextual disabilities, elderly, children), the characteristics of the emergency (e.g. typhoon, earthquake, tornado), the used channel for communicating (e.g. PDAs, smartphones, pagers) and any other exceptional circumstances (e.g. interrupted roads, collapsed exit, dangerous area).

In the fire scenario, the personalization of notified alerts consists of sending an audio recording to the person with a visual impairment in order to guide her through a meeting point and receive the help of an assistant. Users with different abilities would visualize the route with a sequence of 3D images of the environment. In this way, despite the smoke they can orientate themselves and reach an exit.

1.1 The research question

Several organizations and agencies have been promoting the development of Information Technology (IT) tools as notification mechanisms for communicating with common citizens. Such mechanisms are in charge of collecting, updating and notifying information about imminent disasters to potential affected people. In particular, collected information concerns mainly the characteristics of the event (i.e. kind of emergency, urgency, severity), any relevant circumstance (i.e. victims, damages, dangerous areas) and the evacuation procedures if needed (i.e. safe points, shelters, routes).

Existing systems allow sending the notifications through different channels, like websites, emails, text or voice messages. In this way, the personalization consists of choosing a communication channel depending on the device used by the citizen. Neither the characteristics of the emergency and the evacuation procedures nor any other exceptional circumstances (e.g. contextual disability, damaged roads) are taken into account. For example, the evacuation route could change depending on how the emergency affects the environment (e.g. dangerous areas or interrupted roads) or the abilities of the user (e.g. stairs are not accessible for people with a motor impairment).

There isn't a mechanism for making notifications accessible for every *user*, *context of use* and *situation*. Each one of these factors represents specific aspects to take into account for the adaptation. The *user* groups the subscribed profiles with functional and contextual abilities (e.g. visual or hearing impairment, tourists with difficulties in orientating themselves), geographical location, age (e.g. children or elderly) and any other vulnerabilities that could affect the notification mechanism. The *situation* includes the information about the physical conditions of the environment, the official evacuation plan and procedure and the characteristics of the emergency situation. The *context of use* represents the users' devices (e.g. PDA, mobile phone, pager) and the available communication infrastructures (e.g. mobile network or radio signals) for guaranteeing an effective reception of notified alerts.

The research question addressed by this thesis is represented by Figure 1.1 and it can be stated as follows:

> How to establish a deep correlation among the *user*, the *context of use* and the *situation* in order to guarantee the notification of emergency and evacuation alerts for all?

1.2 The hypotheses

Taking into account the such research question, this thesis aims to propose a valid solution proving the following hypotheses:

- Providing personalized information about emergencies and evacuation procedures lies on the definition of a knowledge model.
- The knowledge model is consistent and complete with respect to the *user*, the *context of use* and the *situation*.
- The knowledge model interoperates efficiently with existent solutions in the area of emergency management.

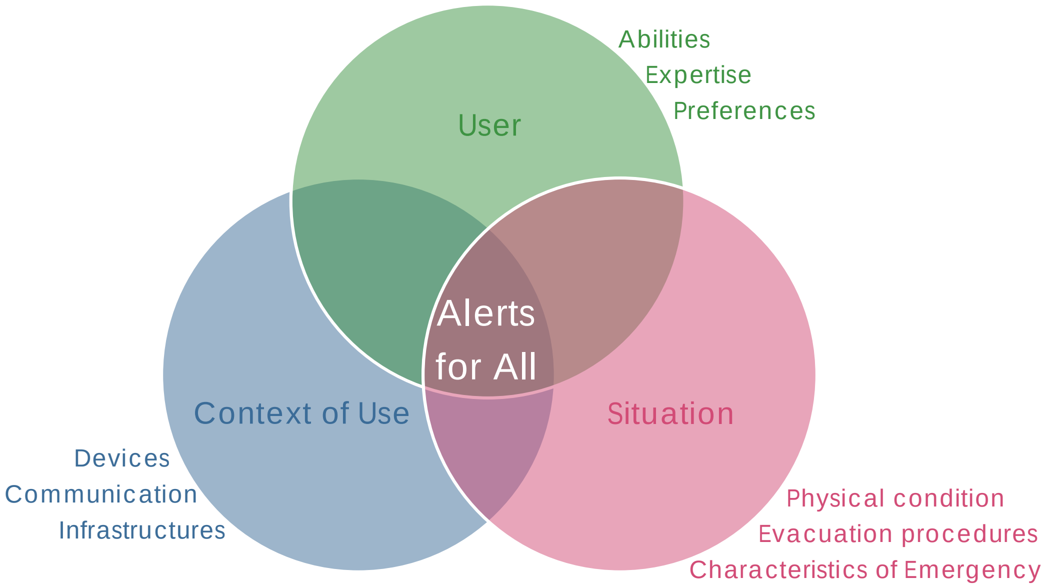


Figure 1.1: The research question

1.3 The solution

The first step to address the research question will be the development of an ontology called SEMA4A (Simple Emergency Alerts 4 [for] All). The ontology aims at establishing a deep correlation among available information about the *user*, the *context of use* and the *situation*. It will not be another IT-based tool, but a conceptual basis that other systems could interoperate with for designing accessible notification mechanisms. This base has been designed as part of a more general architecture (see Figure 1.2). The architecture takes in input the three factors and it is composed by four elements:

- The *Notification Mechanisms* represent the notification systems for alerting about emergencies and evacuation procedures.
- The *Communication Protocols* gather the protocols used for communicating and sharing information about emergencies and evacuation procedures.
- The *Emergency Systems* are the systems for managing information about crisis situations and evacuation procedures.

- The *Knowledge Base* is the SEMA4A ontology used for correlating the other three components.

Based on the characteristics of the three inputs, the *Knowledge Base* module is in charge of adapting the alert notifications. To do this, a deep correlation with the other three components is required. Consequently, the *Knowledge Base* has to be *consistent* and *complete* for representing adequately the three inputs; *understandable* for establishing a comprehensible language for human beings; *interoperable* with existent solutions as notification mechanisms, communication protocols and emergency systems.

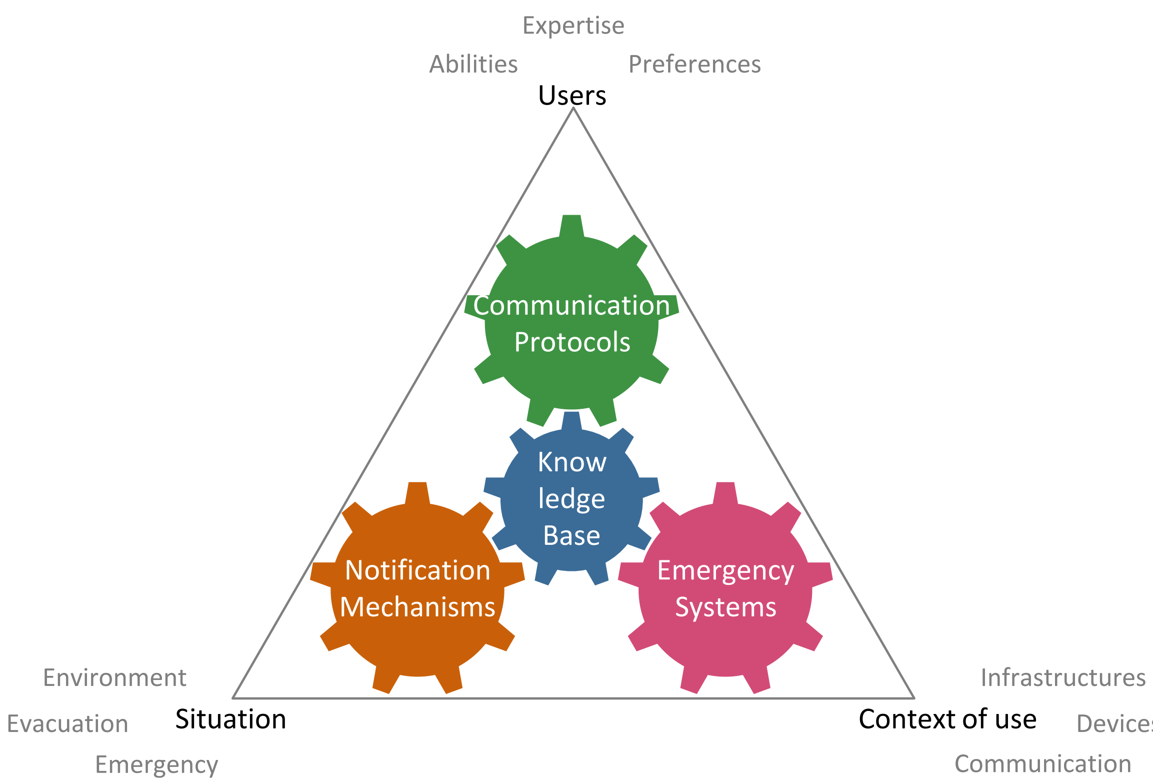


Figure 1.2: The architecture of the proposed solution

In the literature, several contributions have partly responded to the requirements for designing the *Knowledge Base* component. They follow two main approaches: syntactic and semantic. From the syntactic point of view, developed solutions aim at standardizing, communicating and sharing relevant information about emergencies and evacuation procedures among different platforms. An example is the CAP (Common Alerting Protocol) standard that collects and interchanges emergency warnings specifying the urgency, the map with the affected areas and the evacuation procedures (OASIS Emergency Management Technical Committee, 2010). This protocol is currently used by international agencies, as the Federal Emergency Management Agency (FEMA) from the U.S. Department of Homeland Security.

The semantic approach consists in providing affected people with comprehensible and useful information in order to make them aware about what is going on and how to react. To do this, the knowledge behind such information has been modelled as intelligent systems that allow sharing and reusing mechanisms among different IT tools. Examples of such semantic representations are the Emergency Response Ontology (Li et al., 2008) for formalizing the emergency response workflow and the AccessOnto ontology (Masuwa-Morgan and Burrell, 2004) for identifying accessible web elements.

Considering the crucial role of the citizens and the emergency operators for the scope of this thesis, the *Knowledge Base* module is going to be designed as a knowledge representation based on semantic rules: the SEMA4A ontology. In literature, there are not intelligent systems that cover in depth the correlation among the three factors identified by the research question (i.e. *user*, *context of use* and *situation*). In fact, the analysed contributions focus mainly on individual aspects of the adaptation, like characteristics of the emergency situation (e.g CAP and the Emergency Response Ontology) or users' profiles (e.g the AccessOnto ontology).

Consequently, the knowledge representation proposed in this thesis has to cover an articulated knowledge including four domains: accessibility, technology, emergency and evacuation procedures. Each one of these domains represents a different aspect to take into account for adapting the notifications: accessibility for the users' profile, technology for the interactive devices and the communication channels, emergency for the characteristics of the situation and evacuation procedures for the escaping measures.

In order to define a valid mapping among such domains of interest, an intelligent system (e.g. expert systems, neural networks or ontologies) is needed to identify representative concepts and to define complex relations among them. For this reason, this thesis will propose the design and the development of the SEMA4A ontology. Ontologies are powerful semantic models for describing and mapping information related to different knowledge areas. Moreover, several tools based on the first order logic can be used to verify their validity and integrity.

The applied methodology to design SEMA4A has been inspired by the Knowledge Management life cycle defined by Maier in (Maier, 2007). The result is an ontology organized into four main classes: *Accessibility*, *Communication*, *Emergency* and *Evacuation*. Each one of them contains representative concepts for the four domains of interest, mapped among each other through the definition of several ad-hoc relations. Moreover, it has been codified using the Ontology Web Language (OWL), a XML-based standard for ontologies and knowledge models.

To be a valid solution for the *Knowledge Base* module, SEMA4A has to achieve the already pointed out properties: *consistency*, *interoperability*, *completeness* and *understandability*. These properties have been evaluated using well-known instruments from the Ontology Engineering area. For the *consistency*, SEMA4A has been analysed through a reasoning tool called Pellet (Parsia and Sirin, 2004) in charge of finding any redundancies and misunderstandings. For the *interoperability*, formal recommendations for XML-based ontology language published by the World Wide Web Consortium (W3C) have been considered. For the *completeness* and the *understandability*, three statistical functions (i.e. coverage, accuracy and precision) have been computed. In particular, both a quantitative and a qualitative evaluation have been performed. As stated in (Fernández-López et al., 1997), the domain experts have a crucial role in the Ontology Engineering. For this reason, several experts in accessibility, technology, emergency and evacuation have been involved as evaluators. From the interviews with the experts, their opinions about the quality of SEMA4A and any needed improvements have been collected.

The obtained results from the evaluation phase show that SEMA4A achieves each one of considered properties guaranteeing that it is a valid solution for the *Knowledge Base* module.

The applicability of the proposed architecture and in particular of the SEMA4A module has been proved through three use cases: CAPONES, NERES and EmergenSYS. CAPONES is a system that takes in input a standard emergency message (i.e. CAP alert) and sends personalized notifications to subscribed users. The SEMA4A ontology is in charge of correlating the notification mechanism with the emergency message and the users' profiles in order to adapt the content and the used communication channel.

NERES is a client-server application for sending personalized indoor evacuation route. On the server side, NERES interoperates with SEMA4A to relate among each other the information about the emergency situation, the users' profiles and the evacuation procedures. On the client side, the mobile application iNERES is developed for receiving the evacuation routes. The interoperability with SEMA4A makes possible the adaptation of both the route and the visualization mode choosing among text description, image gallery, map and augmented reality.

The last use case is EmergenSYS. The aim of this project is to improve the collaboration between the citizens and the emergency operators. There is a server side in charge of managing the activities performed by the operation centre and a client side with the development of three different mobile applications for the citizens. In particular, SEMA4A ontology is used by the server side for making the notifications accessible considering the users' profiles, the characteristics of the emergency and the evacuation procedures. The adaptation concerns both the content and the visualization mode, as for NERES.

1.4 Thesis Outline

In Chapter 2, the most relevant contributions related to the scope of this research work are surveyed in a review of the state of the art. On the one hand, the state of the art includes the analysis of existent IT-based tools for notifying emergency information and evacuation procedures. This analysis aims at identifying limitations and requirements for designing efficient notification mechanisms. On the other hand, also the most common standard representations for modelling knowledge are introduced. Among them, the ontologies are selected as knowledge representation for the proposed solution. For this reason, the state of the art also focuses on known techniques in Ontology Engineering for developing ontologies.

In Chapter 3, the research methodology followed within the scope of this thesis for analysing the problem and proposing a solution is introduced. Based on the Design Science Research Methodology by Hevner and Chatterjee (Hevner, 2007), the research question and the objectives to achieve are introduced.

In Chapter 4, the solution for the identified research question is proposed: an ontology called SEMA4. Following the research methodology, first of all the objectives are traduced into a set of design goals. Secondly, in order to clarify the scope of the solution, two design scenarios are described. Successively, the design of SEMA4A is introduced through each phase of its development: knowledge identification, knowledge acquisition, knowledge creation and knowledge organization, and implementation. Finally, the usage of SEMA4A is shown with its application to considered scenarios.

In Chapter 5, the proposed solution is evaluated considering the pointed out objectives. In obtained results show that SEMA4A achieve the following four properties: completeness, understandability, consistency and interoperability. Each one of them has been evaluated looking for specific techniques in Ontology Engineering.

In Chapter 6, we are going to show the applicability of SEMA4A through three use cases: CAPONES, NERES and EmergenSYS. All of them are notification systems, but each one offers different services. The SEMA4A ontology is used for adapting the notifications depending on the characteristics of the users, the emergency and the evacuation procedure. In particular, CAPONES aims at sending personalized emergency alerts to subscribed users. NERES and its mobile version iNERES are in charge of alerting adapted instructions to follow in order to escape from the dangerous area and reach a safe place. EmergenSYS is a client-server architecture for improving the communication between the citizens affected by an emergency (i.e. witnesses or victims) and the operation centre.

In Chapter 7, the conclusions of this research work are discussed focusing on the technological and the research contributions. Moreover, not only the advantages but also the limitations of the solution are drawn out and justified. Finally, some future works are proposed to follow up with this thesis.

Chapter 2

The State of the Art

In this chapter, the most relevant contributions related to the scope of this research work are collected. In the first section, we introduce the state of the art in IT-based notification systems for emergency alerts and evacuation procedures with a special focus on personalization and accessible mechanisms. In the second section, we introduce the most common standard representation used for modelling knowledge that could support an adaptable notification and evacuation procedures.

2.1 Personalizing Emergency Alerts and Evacuation

The personalization of information about critical events and evacuation procedures plays a crucial role for the notification mechanisms. Alerting adequately people could facilitate the response activities performed by the operators in charge of managing emergencies. For this reason, governmental and non-governmental agencies have been promoting the development of notification systems for alerting both emergency information and evacuation procedures. In this section, we analyse the main contributions in literature within this scope. First, we present what kind of information is the object of such alert notifications defining the emergency management process and the evacuation procedures. Second, we introduce the IT-based notification systems that have been already developed for communicating information about the emergency and the evacuation procedures.

2.1.1 The Emergency Management Process

The role of governmental and non-governmental agencies in charge of managing crisis situations is to organize the activities to perform for responding, preventing and mitigating such kind of events. These three phases are part of what is known as the emergency management process.

Several authors contributed to the improvement of the emergency management process, focusing in particular on a more efficient organizational structures. In (Waugh and Streib, 2006), Waugh and Streib analyse the structure of the Department of Homeland Security and the Federal Emergency Management Agency in United States and identify the four phases of the emergency management process:

- preventing and mitigating the impact of disasters;
- preparing an emergency planning and training;
- responding with specific actions, including warning systems and evacuation plans;
- restoring the situation with basic services.

Another interesting work has been proposed by Chen et al. (Chen et al., 2008). The authors apply a life-cycle approach to the emergency management process defining a framework with the three different phases:

- the pre-incident phase where evacuation procedures are defined and different risks are analysed;
- the during-incident phase where notification mechanisms are used for alerting citizens and if it is necessary evacuation procedures are started;
- the recovery phase where mitigation activities are performed.

The main difference with the Waugh and Streib's contribution lies in the organization of performed activities in two classes: front-end and back-end. On the one hand, the front-end ones are generally related to a rapid intervention and prevention involving operators in direct contact with the emergency (e.g. firemen and policemen). On the other hand, the back-end class of activities refers to communication and coordination needs with managers in charge of organizing the entire process. This approach has been applied for the Workpad project (Catarci et al., 2008) to develop a peer-to-peer architecture as support for collaboration among operators during disasters. The authors define two different communities of operators, front-end and back-end, offering specific services for each one of them.

In this research work, we focus on the crucial role of notification mechanisms as a key point for the emergency management process, as pointed out by Turoff in (Turoff, 2002). In the contributions of Waugh and Strieb and Chen et al., the notification mechanisms have been defined as part of the response phase. In particular, Chen et al. specify that notification activities are part of the back-end class and they are performed by the operators and managers in charge of the communication and coordination needs.

2.1.2 Alerting Evacuation Procedures and Standards

When an emergency occurs or is going to occur, another crucial task within the emergency management process is related to notifying affected people about which routes can be used for escaping. In order to ensure that everybody can reach a safe place, it is important to take into account several factors, like the characteristics of the environment and the particular needs of users (i.e. contextual or functional disabilities, elderly, social and individual behaviours in panic situations).

Several authors have been working with the common aim of finding an optimal and fast solution for evacuating efficiently the affected population. In order to define procedures and standards to follow, it is crucial to understand which factors have to be considered and how they are related among each other. For this reason, several algorithms represent the area to evacuate as a network with constraints like dimension, number of evacuees and possible bottlenecks. In [2], authors have categorized available algorithms into three main categories: (a) linear programming; (b) simulation methods; (c) heuristic methods.

The main difference among these three categories lies in the objective they propose to reach.

- Linear programming tries to minimize the overall evacuation time looking for an optimal route diagram.

- Simulation methods are based on observing the behaviours of individuals while they are evacuating and trying to predict them.m
- Heuristic methods aims to reduce the computational cost combing and extending existent algorithms [10].

As stated in [1], all considered algorithms require the following list of basic factors as input:

- kind of location, as indoor or outdoor (e.g. buildings, stadiums or entire cities);
- individual behaviours of people involved in a critical situation;
- user profiles, focusing in particular on special needs, as assistants or supports;
- relevant characteristics of emergency and affected areas;
- safe places for people at risk;
- performed activities by emergency operators and managers.

These factors have been considered by governmental and non-governmental agencies to define procedures and standards for developing evacuation plans. The American Society for Testing and Materials (ASTM) has defined a set of standard guidelines to support the identification of valid evacuation route diagrams for buildings (ASTM Subcommittee E34.40, 2003). An evacuation route diagram is composed by a set of signs used to give useful information about how to reach the closest exit or safety point. Trough the standard guidelines, these signs are designed and placed in order to be comprehensible for building occupants.

Another agency involved in the definition of standards for developing evacuation plans is the Occupational Safety and Health Administration (OSHA). The mission of this agency is to guarantee the safety of American workers providing several kinds of facilities in the form of Web-based tools called eTools and eMatrix (Occupational Safety and Health Administration (OSHA), 2013). These facilities can be employed both as reference or training material. In particular, there is a collection of rules and legal issues to take into account when an evacuation is needed.

2.1.3 IT-based Notification Systems for Emergency Alerts and Evacuation

During an emergency, sharing updated information about the situation, such as the area affected by the crisis, the evacuation routes and the safe places, is crucial to make effective decisions and to reduce the number of victims. Within this scope, Information Technology (IT) represents a relevant support for managing communications, processing information, helping in decision making and improving the situational awareness. For this reason, international organizations and agencies have been promoting the development of several IT-based initiatives, like standard formats for exchanging data, client/server applications or complex distributed services architectures (Van De Walle and Turoff, 2007). Next subsections review the broadly accepted communication protocol CAP (Common Alerting Protocol) as well as systems for alerting emergency information and evacuation procedures.

Common Alerting Protocol

The necessity of sharing emergency information and messages in real time among different systems has been addressed by the Organization for the Advancement of Structured Information Standards (OASIS). The aim of OASIS is to define open standards to improve the interoperability and communication among emergency systems. One of them is the Common Alerting Protocol (CAP) (OASIS Emergency Management Technical Committee, 2010). As stated in November 2000 by the National Science and Technology Council in the United States, CAP has been proposed in order to respond to the need of a standard method for collecting and sharing all kinds of information and alerts about disasters.

The CAP protocol is an XML-based data format for collecting and interchanging warnings and emergency information among alerting technologies. Each message is composed by four elements: *alert*, *info*, *resource* and *area*.

- The element *alert* contains information about the message, like scope, source, status and related messages.
- The element *info* provides characteristics about current event, like urgency, severity and certainty, a description of the disaster and details about the response phase.

Figure 2.1: Screen-shot of the Google website taken on March 11, 2011 on the occasion of the Japan tsunami and earthquake(Source: www.google.com)

- The element *resource* concerns additional information related to the disaster as images or audio files.

- The element *area* is a description of the geographic area of the disaster in terms of shape, latitude, longitude and altitude.

Several international organizations and agencies are already using the CAP protocol for sending and receiving emergency information. For example, Google has developed the Alert Hub (Google Crisis Response, 2013), a free service managed by the Google Crisis Response team. The Alert Hub uses the CAP format for receiving and showing emergency information in one of the Google products, as for example in the Google search website. An example of how Alert Hub works is in Figure 2.1 with a screen shot of the Google search website taken on March 11, 2011 that shows an alert about the tsunami and earthquake of Japan. To do this, the Google Crisis Response team has created the CAP community that aims to develop useful tools for the management of CAP messages (e.g. a code library and a validator for checking the syntax).

IT-based notification systems for emergency alerts

The first class of notification systems we are going to consider here are intended to alert people potentially at risk and share updated information about the current situation both with citizens and emergency workers. Within the World Wide Web Consortium (W3C), there is a working group called Emergency Information Interoperability Framework (EIIF)(Emergency Information Interoperability Framework (EIIF) Incubator Group, 2009) whose objective is to identify standards in the emergency management area. One of the activities performed by the EIIF is to categorize the emergency management systems that have been published in these last decades. We have analysed this categorization looking for systems that offer notification mechanisms, selecting twelve of them as shown in Table 2.1. Moreover, for each system we have also considered if it provides any accessible support, like adapting information for people with special needs (e.g. children, elderly, disable people).

Crisis Commander The Crisis Commander is a North American corporation leader in the development of crisis management systems. Developed systems and tools are extensively used by several organizations around the world (Crisis Commander USA, 2013) in major disasters, like the London subway bombing or the Katrina hurricane. In particular, the Crisis Commander has proposed two specific tools for sending notifications: CC Alert and Alert Max. Through CC Alert and Alert Max, agencies can send different kinds of messages (i.e. voice, SMS, email and fax) at the same time with information about the current situation to both mobile and desktop devices. These messages can be delivered to citizens and emergency operators or managers. In this case, neither CC Alert nor Alert Max provides an adaptation mechanism: the sender has to decide both the information to send and the device to use taking into account who is going to receive the message.

Commercial Mobile Alert System The Federal Communications Commission (FCC) of the Public Safety and Homeland Security Department in USA has developed the Commercial Mobile Alert System (CMAS) (Federal Communications Commission, 2013). The CMAS collects emergency alerts published by governmental agencies, validates and categorizes them depending on the kind of the event. Mainly, there are three different classes of alerts: Presidential, Imminent Threat, and Amber Alerts. Successively, through a provider gateway emergency operators select the most relevant alerts depending on their characteristics (e.g. the urgency). These alerts are finally sent to people in the affected area in a CMAS voice format. In order to receive alerts, users have to be subscribed to the CMAS and to use a compatible handsets.

Depending on the special needs of the subscribers, the CMAS could provide audio or vibration signals, wireless services, radio or television. In this case, even if the system offers an adaptation mechanism, the subscribers have to find out a CMAS compatible device in order to be sure that the sent messages are received.

Command Caller The aim of the Command Caller system (Voice Technologies, 2011) is to notify emergency alerts to different kinds of devices, such as PDA, mobile phones, fax and pagers. As in the previous case, also here users have to be subscribed to the Command Caller platform in order to receive the alerts. When an emergency occurs, the operators in charge of communication activities can record both voice and text messages with useful information about the situation. Successively, the system automatically sends recorded messages to the device chosen by the subscribers (i.e. telephone calls, emails, faxes or pages). As an alternative, it is also possible to establish an emergency conference to notify a group of users geographically distributed at the same time. Another characteristic of this system is the possibility to store a log file with a detailed report about the notified users, the calls made and the messages sent.

Finally, the Command Caller system provides an additional module called Command Mapper. The Command Mapper module is a GIS map that allows the visualization and the integration of emergency information with geographic data. Through this module, it is possible to identify the affected area on the map and to keep track of involved resources in the response phase.

Cooper Notification The aim of the Cooper Notification (Eaton's Cooper Businesses, 2013) system is to provide mass notification mechanisms to alert adequately people affected by an emergency situation. As stated in the AboutUs section of its website: "delivering the right message to the right people at the right time is paramount for responding to threats". This system represents a support for the emergency operators that can alert people potentially at risk both in indoor and outdoor environments recording voice and text messages. These messages could include different kinds of information about the event depending on the used notification mechanism.

The Cooper Notification industry provides three different solutions: Distributed Recipient, In-Building and Wide-Area. The Distributed Recipient Mass Notification is in charge of sending alerts to the devices of the subscribers' community, like mobile phones, pagers and personal computers. The In-Building Mass Notification manages emergency communications for notifying crucial information about buildings evacuation. The Wide-Area Mass Notification is similar to the previous solution but, in this case, notified information is about outdoor evacuation.

EmerGeo Fusionpoint EmerGeo Fusionpoint (SIS EmerGeo Solutions, 2013) is a Web-based crisis management system for collecting, visualizing and managing alerts with useful information about actual or potential emergency events. In particular, this system offers a different platform and a set of functionalities depending on the role of the operators from agencies and organizations involved in the emergency management. In this way, it is possible to identify quickly the right operators to alert when an incident occurs in a specific area and to establish an efficient communication channel for sharing information.

The same procedure can be applied to send emails and SMS to subscribed users, focusing in particular on those who are involved in the emergency. Notified information includes a description of the event with the location and the evacuation procedure if needed. For example, in a traffic incident the EmerGeo Fusionpoint can be used to identify on the map vehicles that are passing thorough the affected area.

NC4 E•SPONDER The National Center for Crisis and Continuity Coordination (NC4) is in charge of providing support to the agencies and organizations involved in the management of crisis situations. Within this scope, the center has developed different solutions for managing emergency communications. The first one we are going to consider here is called E•SPONDER (NC4 Street Smart, 2013a), a software for sharing and administrating critical information during all phases of the emergency management process. This system has been developed as a framework with different modules that can be modified or added depending on the needs of each particular agency. One of them is the E•SPONDER Alert Module that allows to establish a communication channel for sending notifications about disasters to potential victims, team members and volunteers. In order to receive alerts, users have to be provided with mobile or desktop devices, like mobile phones, PDA, pagers or personal computers. Once the communication channel has been established, it can be used for enhancing the collaboration among involved people, both common citizens and emergency operators. Another interesting characteristics of the alert module is the log mechanism for storing and monitoring outgoing and incoming messages.

Global Disaster Alert and Coordination System (GDACS) The Global Disaster Alert and Coordination System (GDACS) (De Groeve et al., 2006) is a web platform developed by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and the European Commission. It is intended for sending emergency alerts and exchanging information. Moreover, through the GDACS it is possible to coordinate the efforts of international agencies and organizations involved in the response phase.

Collected data from several kinds of disasters (i.e. earthquakes, tsunamis, floods, volcanoes and cyclones) are successively analysed as part of two different activities. On the one hand, emergency operators identify the most crucial information to publish on the GDACS website and to alert the affected community via emails and SMS. On the other hand, data about current and past events are combined with demographic and economic studies to have an idea about expected risks for future crisis. Also the results obtained from this analysis are notified to the population via email, fax and SMS.

NC4 Mission Center™Global Situational Awareness The second solution developed by the National Center for Crisis and Continuity Coordination (NC4) (NC4 Street Smart, 2013b) that we are going to consider here is the NC4 Mission Center™Global Situational Awareness. This system has been developed for supporting the specific needs of public and international organizations and enhancing the collaboration among them in order to manage large-scale crisis. In particular, the NC4 Mission Center™collects useful information about current events from all over the world and keep them updated. This information is successively used to alert both emergency operators and affected citizens through different kinds of devices: mobile phones, computers, PDA, smart phones and pagers.

Additionally, the NC4 Mission Center™offers the possibility to personalize sent notifications depending on the specific characteristics of the emergency, including the severity, the type and the location respect to the area of competence of involved organizations.

Rapid Reach Rapid Reach is a system for communicating information during emergency situations that has been developed by the Enera group with five companies from United States, United Kingdom, Germany, Scandinavia and Singapore (Enera, 2013). Users that want to be reached by this service, have to subscribe their personal device to a contact list, choosing among mobile phones, pagers, faxes, beepers and computers.

When an emergency occurs, Rapid Reach starts to call or send messages to users that could be affected by the crisis taking into account the kind of device they have. This communication can be established both manually by emergency operators or automatically by a predefined set of actions called scenario. In this last case, the scenario can be activated by remote commands or interoperating with external systems. Once the communications are established, users and emergency operators can access to updated information generating also useful reports about the current situation. Moreover, another interesting characteristic of the Rapid Reach system is the interoperability with other emergency systems. In this way, it is possible to collect and share information among emergency workers during the management process and to extend the available list of subscribers to alert.

Send Word Now Alerting Service The Send Word Now company (SWN Communications, 2013) has been founded in order to contribute to the lack of an efficient communication during emergency situations like the September 11 attacks. Among the offered services, there is an alerting service that aims at establishing a two way communication channel with a selected group of users. On the one hand, the users can receive emergency alerts choosing the most useful device for their needs, including email, voicemail or mobile messages for PDA, smartphones or mobile phones. In this way, the service provides a personalization mechanism that allows subscribers to choose which alerts receive and which devices to use.

On the other hand, users that have been alerted about the emergency can respond with relevant information about themselves and their current situation. The system collects such information to create a specific repository for tracking, communicating and auditing purposes.

Another interesting characteristic of the alerting service by Send Word Now is the interoperability with other services developed or not by the same company. International organizations can take advantage of this service including it in the existing emergency systems or platforms.

Sahana Eden Sahana Eden is an open source framework developed by the Sahana Software Foundation, created after the Indian tsunami in 2004. This foundation aims to give a technological support to the operators in order to improve the efficiency of response activities in emergency situations. Within this scope, the Sahana Eden framework is composed by a set of customizable modules and libraries organized in a flexible architecture (Careem et al., 2006). In this way, it is possible to adapt the system in order to respond to the needs of the particular emergency situation or organization to manage. The last deployment of Sahana has been used in 2012 for managing several wildfires spread in Chile.

The framework provides a set of core modules (*Organization Registry*, *Request Management System*, *Shelter Registry* and *Missing Persons Registry*) and optional modules (*Volunteer Coordination System*, *Child Protection System*, *Inventory Control and Catalog System*, *Situation Mapping*, *Data Import* and *Mobile Messaging*) (Currion et al., 2007). In particular, the *Mobile Messaging* module is in charge of sending and receiving alerts with updated information about the emergency situation via emails, SMS, Twitter and Google Talk. Moreover, these communication channels allow users to send short requests to Sahana Eden in order to receive specific information.

Ushahidi Ushahidi (Ushahidi Team, 2013) is a free and open source platform for collecting information about crisis situations. As in case of Sahana Eden, also Ushahidi has been developed as a customizable architecture that can be implemented and adapted depending on specific characteristics of the crisis. The first time it has been used was in 2007 for an election crisis in Kenya. Thanks to

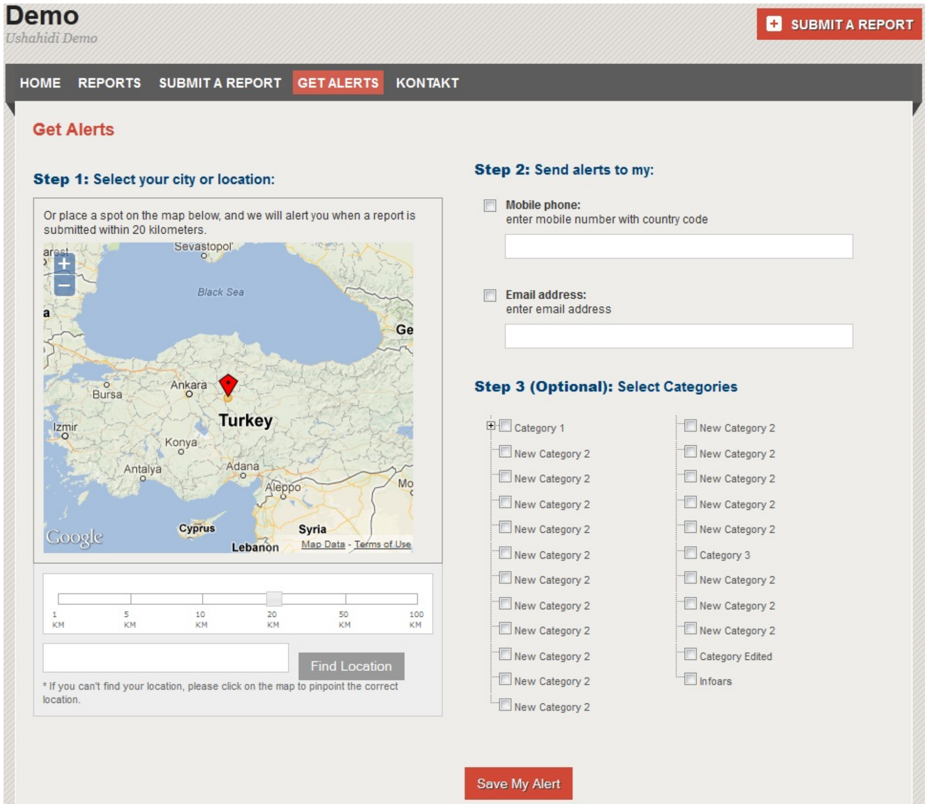


Figure 2.2: Demo for the Alerting Service of Ushahidi (Source: demo.ushahidi.com)

Ushahidi, the affected people received reports about the situation and collected them in repositories creating a background for future events (Okolloh, 2008).

The Ushahidi platform provides several services as support for the emergency management. One of them is the visualization tool for interactive maps that allows operators to associate emergency reports with the related geographical position. Another one is the alerting service to send notifications as SMS or emails to mobile or desktop devices. Through this service users can also subscribe to a RSS feed, select interesting categories and receive new reports published on the website. Figure 2.2 shows the demo deployment for the alerting service of Ushahidi.

Table 2.1: Comparative survey of the notification systems with accessible facilities

System	Website	Notification	Accessibility
Crisis Commander	(Crisis Commander USA, 2013)	Voice messages, SMS, email, fax	No
CMAS	(Federal Communications Commission, 2013)	CMAS compatible handset	Yes
Command Caller	(Voice Technologies, 2011)	PDA, email, mobile phone, fax, pager	No
Cooper Notification	(Eaton's Cooper Businesses, 2013)	Mobile phone, SMS, email, pager, desktop	No
EmerGEO	(SIS EmerGeo Solutions, 2013)	Email	No
NC4 E•SPONDER	(NC4 Street Smart, 2013a)	Mobile phone, email, SMS, PDA, pager	No
NC4 Mission Center	(NC4 Street Smart, 2013b)	Email, SMS, PDA, smart phones, pager	No
GDACS	(De Groeve et al., 2006)	Email, SMS	No
Rapid Reach	(Enera, 2013)	Mobile phone, pager, fax, email, SMS	Yes
Send Word Now	(SWN Communications, 2013)	Email, voicemail, PDA, smartphones, mobile phones	Yes
Sahana Eden	(Careem et al., 2006)	Email, SMS, Twitter, Google Talk	No
Ushahidi	(Ushahidi Team, 2013)	Mobile phone, email, RSS feed	No

IT-based notification systems for evacuation procedures

Based on the identified procedures and standards, the Security Departments are in charge of applying them, not only to develop an efficient evacuation plan, but also to notify affected people with instructions for reaching safe places. Several IT-based systems have been developed in order to support and improve this task. In this research work, we are interested in understanding how such systems deal with customizable routes and accessible facilities. In Table 2.2, we have summarized the most relevant results that we have found.

CodeRed The CodeRed system (Emergency Communications Network, 2013) has been developed by the City of Mansfield for managing emergency communications in case of an evacuation is needed. People can subscribe to this service indicating a telephone number and the area of interest. When an emergency occurs in that area, the system tries to call the subscribers delivering them a recorded message about what is going on and available procedures to escape.

This system represents an efficient answer for that situation in which a rapid notification is crucial for saving lives. Moreover, it provides an additional service for weather alerts. Subscribers can choose to be alerted about incoming weather emergencies as they have been notified by the National Weather Service.

The Digital Building The Digital Building system (Archaio - The Digital Building, 2013) has been developed to be used during the response phase of the emergency, but also for preparedness and recovery purposes. Depending on the phase the operators are working at, the system can support different activities: locating safety resources, developing an evacuation plan, sending personal evacuation routes to subscribers, or recovering from the critical situation to a normal one.

Among these activities, we focus our analysis on the notification. When an evacuation is needed, the system sends alerts to users with information about how to escape and the nearest safe places. This information is based on several variables, as the user's location, the physical environment and the kind of emergency. These variables are setted manually by the sender. Moreover, as an improvement for this and other services the Digital Building integrates also GIS data in order to offer a more detailed geographical information to users.

Huens The Harvard University has developed an emergency notification system for alerting the Harvard community in case of emergency (Harvard Campus Services, 2013). In particular, the MessageMe service is in charge of managing the communication with the users sending them information about the situation and the available evacuation procedures if they are needed. Each user can specify what kind of device they want to use for receiving the notifications among text or voice emails, SMS or social network messages through Twitter and Facebook accounts. The notified information is the same for the entire community and includes general evacuation procedures that can be applied from everywhere in the campus. Moreover, the Huens also uses traditional communication channels as the University mail account, the Harvard University website or other public media.

Cucem As in case of the Huens system, also the Clemson University has defined a complex emergency management plan that includes different services for different phases of the emergency: planning, response and recovery. Within the response phase, the Cucem (Claremont University Consortium, 2013) is a notification service in charge of managing the available communication channels. The aim of Cucem is to alert the entire community in the campus or in the restricted area to evacuate if a critical situation occurs. To do this, the service does not consider the personal devices of involved users, but public media as television and radio channels or siren warning systems.

cAlert The cAlert system (The University of Chicago, 2013) has been developed by the University of Chicago is order to notify critical situations of the community. In particular, when an emergency occurs the operators write or record a text message that is successively delivered to subscribers as SMS, emails or phone calls. As in the previous case, the sent messages contain information about general evacuation procedures that can be followed from every locations in the campus. Once the message has been received, the user is asked to send a confirmation. The confirmation is used by the operators to check the status of the affected people and, in particular, to determine if more help is needed or not. Due to its characteristics, the cAlert has been developed specifically for situations that require immediate actions for saving lives.

Inoues et al.'s system In 2008, Inoue et al. have proposed an indoor emergency evacuation service based on autonomous navigation system for providing user's location based notification message (Inoue et al., 2008). When an emergency occurs and an evacuation is needed, users receive the notification through a mobile application where the map of the building is visualized with available facilities and safety points. Moreover, the application sends a textual description of the instructions to follow for reaching an exit and a speech function that can be used by disabled and elderly users. Once the message has been received, the user can choose one of these two modalities (i.e. text or audio) to access the instructions. Moreover, the notified instructions allow users to reach the nearest exit depending on their location, but they do not consider exceptional circumstances that could block the selected route.

Table 2.2: Analysed Emergency Notification and Evacuation Systems and their main features

System	Reference	Notification	Personalization	Accessibility
CodeRed	(Emergency Communications Network, 2013)	Phone call	Yes	No
The Digital Building	(Archaio - The Digital Building, 2013)	No	Yes	No
Huens	(Harvard Campus Services, 2013)	social networks, SMS, text and voice emails	No	No
Cucem	(Claremont University Consortium, 2013)	Radio, TV	No	No
cAlert	(The University of Chicago, 2013)	SMS, phone calls, emails	No	No
Inoues et al.'s system	(Inoue et al., 2008)	Mobile application	Yes	Yes

2.2 Knowledge Representation

Since this work aims at modelling an articulated knowledge trough a semantic based representation, in this section most relevant contributions for Knowledge Representation are introduced.

In these last decades, the increasing need of sharing knowledge among different platforms has highlighted the lack of a standard organization for creating, managing, representing and distributing common concepts and theories. Researchers from different disciplines have been working on new approaches for contributing to this lack as part of the interdisciplinary area known as *Knowledge Management* (KM). The KM area joints branches from different research fields (i.e. from business administration and management to information systems) for an extensive variety of subjects.

A detailed description of each research field included in the KM discipline has been proposed by Maier in (Maier, 2007), as for example the *organizational memory*, the *organizational intelligence* or the *sociology of knowledge*. The scope of this research work is situated within the sociology of knowledge looking for a conceptualization of a collective knowledge, where identified concepts and theories are the result of an organizational learning. The role of Information Technology is to support this conceptualization, making the knowledge formal and explicit for the users through the development of practice Knowledge Representations (KRs).

The conceptualization of a knowledge area (i.e. *domain of interest*) and consequently the definition of a KR are complex tasks that have been approached with different techniques in literature. In (Maier, 2007), Maier identifies eleven main classes of general tasks to identify, acquire, create, organize, publish, distribute, search and retrieve, apply, evolve, delete and archive a collective knowledge with the collaboration of involved participants. Considering the scope of this research scope, we focus on four main classes: *Knowledge Identification*, *Knowledge Acquisition*, *Knowledge Creation* and *Knowledge Organization*.

- The *Knowledge Identification* aims at identifying sources for retrieving knowledge. Such sources could be both internal and external respect to the considered domain. In this way, it is possible to define an extensive set of documents, called *corpus*.

- The *Knowledge Acquisition* aims at acquiring knowledge from sources previously identified. Mainly, there are three different kinds of sources: the working experience of human operators, the literature (i.e. books, reports, journals or other professional databases), the collaborative events (i.e. conferences or workshops).

- The *Knowledge Creation* is composed by the tasks for extracting relevant knowledge from the sources previously acquired. The creation phase is supported by the individual and collective learning process and for this reason it is possible to provide facilities for enhancing the interaction, the discussion of ideas, the creativity and the organizational culture.

- The *Knowledge Organization* consists of defining relations among identified concepts and theories. The result is a knowledge structure that can be implemented using a KR, like an ontology or another mapping tool.

In literature, different KRs have been proposed in order to cover different organizational needs. To choose a particular representation is crucial to understand what characteristics have to be emphasized or ignored within a topic and to identify which KR technique could capture them.

Defined KR techniques can be categorized into three main forms (Grimm et al., 2007): *Semantic Networks*, *Production Rules* and *Logic*.

- The semantic network is a graph with vertices and edges, where the vertices represent the concepts extracted from the knowledge and the edges represent the relations among the concepts. Each triple over the graph composed by two vertices and an edge gives a representation of a relevant sentence for the domain of interest.

- The production rule is a set of IF-THEN rules for structuring complex statements about a specific knowledge. The advantage of this approach lies in the possibility of deriving easily implicit information about the domain of interest from already defined rules.

- The logic as KR consists of representing the knowledge through a formal language that allows to create true or false statements. In order to achieve it, it is needed to define three elements: (a) a syntax (i.e. a set of rules to form the sentences), (b) a semantics (i.e. the right interpretation for the sentences in the domain of interest), (c) a proof theory (i.e. a set of rules to derive new sentences from the already defined ones).

A part from these three categories of KR, recently the notion of ontologies has been adopted as a possible representation for complex domains. While in Philosophy the term *Ontology* has been used for referring to the study of *being* and its fundamental *categories*, during the 90s this concept has been applied in the area of Artificial Intelligence as a formal vocabulary to represent and share knowledge about a specific domain (Gruber, 1993). In 1995, Guarino and Giaretta have clarified the distinction between *ontology* (with a small *o* as initial) for the knowledge object and *Ontology* (with an initial capital) for the philosophical discipline.

In literature, it is possible to find several definitions for the ontology as KR, as summarized in the survey published in 2004 by Gómez-Pérez, Fernández and Corcho (Gómez-Pérez et al., 2004). In 1993, Neches et al. defined the ontology as an *"explicit specification of a conceptualization"* with terms and relations, where relations are formal axioms that clarify how these terms have to be interpreted and used. This definition became the most quoted in the knowledge community and the basis for successive contributions. The other definitions differ from this for the point of view authors have adopted: the development process, the scope or the applicability. Nevertheless, all of them share the same idea about the interdisciplinary and the collaboration, stating that *"ontologies aim to capture consensual knowledge in a generic way"* (Gómez-Pérez et al., 2004). This means that an ontology can be used also for establishing a common and formal language to make interoperable different domains of interest, as we are going to do in this research work (more details in Chapter 3).

In (Gómez-Pérez et al., 2004), authors have also introduced the research area of Ontological Engineering as *"the set of activities that concern the ontology development process, the ontology life cycle, and the methodologies, tools and languages for building ontologies"*. Within this scope, the development an ontology as KR is strictly related to used techniques for modelling it. Moreover, it is a complex task that requires an accurate analysis of domains of interest in order to extract relevant information and represent it through concepts and relations among them.

In literature, authors have been working on different approaches for the applied development process: building from scratch, merging or evolving from a previous version, using software patterns, reusing existing ontologies, collaborating on a common knowledge. Each one of these approaches identifies a different category for the development methodologies, as detailed in the extensive survey authored by Staab and Studer (Staab and Studer, 2004).

Building ontologies An example of methodology in this category is the one proposed by Noy and McGuinness in 2001 (Noy and McGuinness, 2000): authors suggest general guidelines without specifying any activities to carry out. The proposed life cycle consists of seven steps:

1. *Domain and scope*. In this initial step, it could be useful to clarify which is the domain and the scope of the ontology to build. This information is helpful to determine limitations, coverage and competencies of the entire process.

2. *Reusing*. Reusing existing ontologies in the same domain can simplify the development process. In this case, the entire building process is reduced to translate or extend other contributions. In literature, there are several open-access libraries that allow developers to reuse published ontologies for their scope.

3. *Important terms*. From this step, the building process starts with the identification of relevant terms within the considered domains. A way to determine which terms are most important is making statements for explaining the domain to an user.

4. *Classes and Class hierarchy*. Once terms have been identified, they are grouped into classes. To do this, there are three main methods: top-down, bottom-up and combination. The top-down method determines the most general class and successively more specific subclasses until reaching individual concepts. The bottom-up method starts from specific concepts and then defines the entire hierarchy with most general classes. The last method is a combination of the previous ones analysing firstly both most general and most specific concepts.

5. *Slots*. In order to characterize defined classes, specific properties are needed. Such properties are like slots attached to each class to describe its structure through different aspects: intrinsic, extrinsic, physical or abstract parts, relations with other classes.

6. *Facets of slots*. Once properties have been defined and associated to classes, the next step concerns the identification of different facets for each slot. Examples of facets are represented by the value type, the cardinality, the domain and the range.

7. *Instances*. The last step of this methodology consists in instantiating the hierarchy of classes, associating a value to each slot. Created instances differ for the slot values.

Evolving ontologies Among methodologies for evolving and reengineering ontologies, there is *Methontology* presented in 1997 by Fernández, Gómez-Pérez and Juristo (Fernández-López et al., 1997). Within the development process, defined activities are organized and scheduled with a life cycle approach where the ontology evolves at each stage through improved versions. The life cycle consists of seven steps:

1. *Specification*. During the specification phase, a formal or semi-formal structure is defined with information about the purpose of the ontology, level of formality, terms to be included with their characteristics and granularity, any references to other contributions and authors profiles. The final structure has to be concise, complete and consistent. These requirements can be traduced in choosing each term to be relevant, meaningful, unique, granular and with an high coverage over the domain.

2. *Knowledge Acquisition*. The aim of this phase is to identify sources for retrieving concepts about a specific domain and successively analysing their meanings for selecting just most relevant ones. There are several techniques to do this, as for example interviewing domain experts, brainstorming, using knowledge acquisition tools or existing ontologies.

3. *Conceptualization*. The structure and the list of relevant terms defined in previous steps are used here for the definition of a conceptual model with the description of the proposed solution. Terms are grouped into concepts and verbs for identifying relations and rules using classification trees and diagrams.

4. *Integration*. During the integration phase, other ontologies already defined in the same or similar domains are considered for reusing purpose and speeding up the development process. A crucial point in this case is the coherence between the conceptual model already defined and the semantics of terms and relations to reuse. Result of this phase might be an integration document with information about which ontologies have been reused, added terms and relations and their original definition.

5. *Implementation*. Using an appropriate environment as support, as for example lexical and syntactic analysers, this phase considers the structure and the concept model already defined to implement the ontology.

6. *Evaluation*. During this phase, evaluation documents are produced in order to inform about employed techniques, results and possible errors to solve.

7. *Documentation*. As already seen in each one of previous phases, the documentation involves the entire life cycle requiring the collection of appropriate documents to explain performed tasks and obtained results.

Software development Based on software engineering principles, an interesting methodology has been proposed by Devedžić in 2002 (Devedzić, 2002). This approach interprets the ontology development as an object-oriented design, adopting its techniques and properties. In particular, Devedžić underlines several parallelisms that can be used for defining the ontology life cycle.

First of all, objects like classes, methods and interfaces are replaced by semantic elements as concepts and relations, but in both cases these are organized into hierarchical structure (e.g. networks or graphs). Secondly, apart from a different granularity, steps and tasks of the development process can be easily reused, in particular for merging and refining ontologies. Moreover, the usage of templates in software engineering can be interpreted as reusing mechanisms for ontologies.

Reusing existing ontologies Reusing mechanisms are already included in several methodologies, as for example Methontology or Devedžić's approach. The contribution of Paslaru and Mochol does not define any merging algorithm, but combines existing ontologies depending on the formality (Paslaru Bontas and Mochol, 2005).

The aim of this methodology consists of establishing a common vocabulary of concepts, relations and rules combining categories already in source ontologies. Another way to do this is starting from an initial conceptualization and refining it considering both source ontologies and domain experts. A crucial point of such process lies in duplicates of similar concepts. For this reason, the author proposes to compute the semantic similarity between two elements and add similar words as properties of selected concepts.

Community-based ontologies In the above categories, we have not considered the collaborative aspects. Here, the development process is based on contributions made by a community of knowledge, understood as a group of experts in a specific knowledge. Within this scope, an example is represented by HCOME (Human-Centred Ontology Engineering Methodology), a methodology for the development and evaluation of ontologies in the context of communities of knowledge workers (Kotis and Vouros, 2005). It proposes a human-centred approach, where members of the communities participate actively in the ontology life cycle. In order to enhance participation, the workers should be empowered with proper tools for easily submitting and sharing information.

The methodology HCOME structures the development process into three phases: specification, conceptualization and exploitation. the aim of the specification phase is to identify the scope of the ontology, knowledge sources to consider and members of the working group. Activities as acquiring knowledge, promoting participation, consulting domain experts and importing ontology libraries are parts of the conceptualization phase. Finally, the exploitation phase concerns the usage and the evaluation of the ontology. After evaluation tasks and according to obtained results, the community returns to the specification phase in order to apply possible changes. When a consensus among all collaborators is reached, the final version of ontology is ready to be published and used for any application.

2.2.1 Examples of Knowledge Representations

In the domain of accessibility, there are several examples of ontologies developed for semantic purposes, such as establishing a common and formal languages to make interoperable different services. The first contribution we are going to consider here is the KAICO system from the OntoQuercus group (Lozano-Tello et al., 2004). The aim of this ontology-based system is to add semantic tags to web pages in order to extract and communicate information to blind people. The ontology, called OntoSaw, has to relate concepts from web pages to concepts from accessibility domain in order to determine if elements of considered web pages are accessible or not. The employed methodology in this case consists of interviews to people with visual impairments about their experience with a group of web applications. Successively, collected opinions and suggestions are analysed through the WCAG (Web Content Accessibility Guidelines).

Another interesting example similar to the previous one is Dante, a semi-automatic tool for making accessible web pages for people with visual impairments (Yesilada et al., 2004). This tool aims to apply accessible elements to web pages in order to improve the navigation. For achieving this objective, it applies concepts from an ontology called WAfA to transform (or *transcode*) web pages through annotations and tagging mechanisms. The WAfA ontology (Web Authoring for Accessibility), also known as the Travel Ontology because it is based on the analogy of web navigation as a trips for tourists, collects concepts and relations for modelling automatically the structural organization and navigation of web pages (Harper and Yesilada, 2007). This ontology is used by Dante as a controlled vocabulary for describing annotations and transformations.

A different approach has been adopted by the Businesses school of the Canterbury Christ Church University with the development of AccessOnto. The aim of this ontology is to conceptualize a set of semantic requirements for accessibility using a knowledge base built on user profiles (Masuwa-Morgan and Burrell, 2004). The considered base includes two kinds of knowledge: declarative knowledge extracted from a set of web accessibility guidelines, interface objects and user profiles, and procedural knowledge composed by production rules capturing the ideas of adaptive programming and multiple relations management (entities and dependencies). Included guidelines have been collected from several companies and agencies, like

WCAG, Sun Micro System, IBM, Microsoft and Apple.

Considered ontologies present several limitations that make them different.

- Within the KAICO system, the code generation defined in the OntoSaw ontology is not portable for some screen readers and browsers. Moreover, it considers just visual impairments.
- The WAfA ontology encapsulates extensive knowledge to make explicit structural and navigation information of a web page. This approach is more complex than the previous one, nevertheless it presents some problems related to the loss of users' context due to difficulties screen readers could have.
- AccessOnto as a requirements engineering ontology for accessibility should consider existent contributions in the same area, but it just extracts and structures information from fixed sources. Moreover, the ontology is at an early stage and for this reason it has not be implemented with a standard language like OWL.

Other interesting examples are in the domain of emergency, where few ontologies have been used for improving the emergency management process and standardizing a common knowledge base. Most relevant contributions are focused on the response phase and in particular on the lack of a common language among different organizations and agencies. One of them is an emergency response ontology that has been built by Li et al. in 2008 (Li et al., 2008). The aim of proposed ontology is to provide crisis information management systems with a shared semantic representation of the emergency response workflow. In this way, it is possible to automatically infer which is the next action to perform and who is in charge of its execution.

In another interesting contribution, Araújo et al. propose a set of ontologies as support for the generation of different kinds of training simulations specific for fire emergencies (Araújo et al., 2008). In particular, five ontologies have been defined, each one in charge of a different aspect of the simulation activity:

- *Emergency* represents characteristics of the emergency situation, as fire causes and origins;

- *Infrastructure* collects concepts about safety procedure for fire risks, locations and others resources as monuments or buildings;
- *Person* identifies different roles and responsibilities within the simulation activity;
- *Tactic* represents procedures and tasks performed during the simulation activity;
- *Object* concerns several supplies used during the emergency preparedness or response.

Chapter 3

Research Methodology and Problem Identification

3.1 Research Methodology

In this thesis, the different phases of the research work (i.e. problem identification, objectives, design and development of the solution, evaluation) have been structured following the Design Science Research Methodology defined by Hevner et al. in (Hevner et al., 2004). According to this methodology, in order to find a valid solution for the identified problem and objectives, it is crucial to analyse the state of the art focusing not only on existing systems or tools but also on theories, methods and procedures. So that there is a contribution both in the technological and theoretical environments. With this purpose, research is organized around three cycles (Hevner, 2007): the *Relevance Cycle*, the *Design Cycle*, and the *Rigor Cycle* (Figure 3.1).

The Design Science Research Methodology is specific for Information System research and it is inspired by the problem-solving paradigm. It is composed by three main elements: the environment, the design science research and the knowledge base. The environment is the application domain including the collection of existing systems or tools, people and opportunities. The design science research is the central point of the framework including the activities related to the design, the development and the evaluation of the solution. The knowledge base represents the rigorous foundation for the entire research work and it is composed by theories, methods, experience, expertise, design products and design processes.

The three design science research cycles are defined over these three elements.

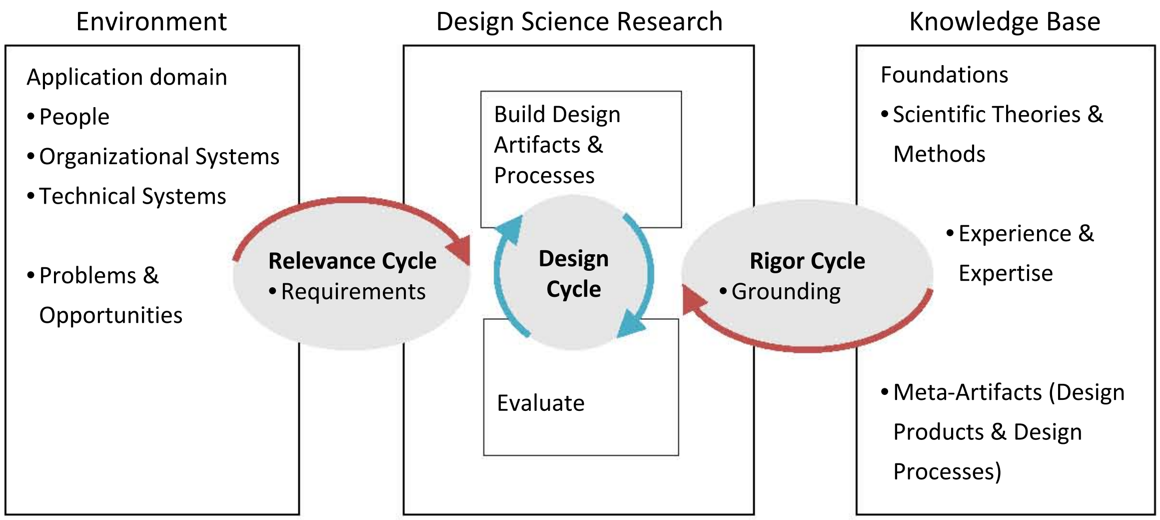


Figure 3.1: The input phase of the Design Science Research Cycle by Henver and Chatterjee (Hevner, 2007)

In particular, the relevance cycle aims at extracting the requirements (i.e. the research question and its motivations) for the design cycle, while the rigor cycle suggests the theories and methods to apply for achieving them. In this way, the design cycle receives information from both the application domain and the foundations in order to design, develop, evaluate and eventually redesign the solution. Once the solution has been developed, it is tested in the application domain and it is included in the foundations as new knowledge closing the cycles.

The environment for this thesis is represented by the exiting emergency and evacuation systems as listed in Table 2.1 and Table 2.2. The methodologies about the emergency and evacuation procedure as well as the methods included in the discussion about the knowledge representation area, are part of the knowledge base (Chapter 2). The research question arises from the analysis of the environment supported by the knowledge base. This is the initial step of the design cycle, as shown in Figure 3.1, where the two red arrows represent the inputs for the design cycle (i.e. the research question and the objectives extracted from the environment, and the theories applied from the knowledge base). In the next chapters (Chapter 4 and Chapter 5), we are going to focus on the remaining steps of the design cycle (i.e. the design and development of the solution, its evaluation and testing).

3.2 Problem Identification

A crucial activity for reducing the number of victims and damages in an emergency scenario is to timely alert people potentially at risk and eventually guide them to safe places. The effectiveness of this activity depends on several factors. First of all, affected people could have different needs, abilities and expertise to take into account for sending them the most useful information and guaranteeing an efficient evacuation procedure. It is important to highlight that during an emergency situation all people could become disabled in some sense because of exceptional circumstances like stress, unknown environment, restrictions or lack of information. Secondly, the notification mechanism depends also on the available technology: for example, some communication channels could not be available due to damages or other circumstances. Finally, it is important to take into account any other information related to measures to carry on as response to the particular situation, as for example damaged roads that could affect the available evacuation routes.

From these considerations, we frame our research goal as using technology for making alert notifications on emergency and evacuation procedures accessible for every user, depending on context and available infrastructure.

In order to understand the complexity of this problem, take for example a building where a fire is occurring. In order to alert all people in the building, we might use audio notifications instead of visual ones since smoke can reduce visibility. Nevertheless, in case of evacuation (e.g. a tornado warning), visual notifications like signs or maps are the most useful artefacts for communicating available routes and procedures to affected people. A similar consideration can be drawn in case of user with visual impairment where audio notifications can compensate her disability.

In such scenario, Information Technology (IT) represents a valid support not only for broadcasting available information but also for personalizing and improving communication and decision making. Several governmental and non governmental agencies have been promoting the development of IT-based tools for emergency management, involving a wide variety of technologies: from mobile and desktop applications to more complex distributed services architectures (Van De Walle and Turoff, 2008).

In Chapter 2, we have analysed several IT-based notification systems for emergency alerts and emergency procedures as part of the application domain of this thesis. The goal of the performed analysis was to understand how these systems deal with personalization and accessible mechanisms. Obtained results (summarized in Table 2.1 and Table 2.2) show that all of them allow users to choose the kind of device to use for receiving notifications among several standard communication channels, like SMS, emails or RSS feed. Just few of them offer the possibility to send both audio and textual contents or vibration signals. In particular, the subscribers to the Commercial Mobile Alert System (CMAS) (Federal Communications Commission, 2013) and the Alerting Service of the Send Word Now platform (SWN Communications, 2013) have the possibility to chose which kind of alert they want to receive. Moreover, they can also specify which device they want to use for any further communication. Another interesting example is the notification system for evacuation procedures proposed by Inoues et al. (Inoue et al., 2008) that sends messages in form of textual description and includes a text-to-speech function for disabled and elderly users.

Offered mechanisms do not automatically determine the device or the content to notify. The user is required to specify this information during the subscription. Moreover, neither the characteristics of the emergency and the evacuation procedures nor any other exceptional circumstances (e.g. contextual disability, damaged roads) are taken into account. There is a lack of mechanisms for adapting notifications to the users' needs and the context, guaranteeing also the interoperability with the available communication infrastructure and platforms. This thesis aims at finding an efficient and effective answer to this lack.

In the knowledge base of this work, several contributions in this direction have been collected. Among them, two main approaches can be recognized: syntactic and semantic. From the syntactic point of view, the idea is to standardize, communicate and share relevant knowledge about emergencies and available evacuation procedures among different platforms, technologies and infrastructures. An interesting example is the CAP (Common Alerting Protocol) standard (described in section 2.1.3) (OASIS Emergency Management Technical Committee, 2010) developed by the Organization for the Advancement of Structured Information Standards (OASIS). The aim of this protocol is to collect and interchange warnings and emergency information among alerting technologies, where communications are mainly focused on characteristics of the emergency, like urgency, affected areas, maps, evacuation procedures. The Federal Emergency Management Agency (FEMA) from the U.S. Department of Homeland Security employs CAP for both coordinating the entire emergency management process and informing about the current situation through communication channels.

The aim of the semantic approaches is to provide affected people with comprehensible and useful information in order to make them aware about what is going on and how to react. This adaptable mechanism refers not only to the content of the message, but also to its rendering and the device used for the notification.

Within this scope, several intelligent solutions have been developed in order to model needed knowledge and allow sharing and reusing mechanisms among different IT tools. Examples of such semantic representations are the Emergency Response Ontology (Li et al., 2008) for formalizing the emergency response workflow and the AccessOnto Ontology (Masuwa-Morgan and Burrell, 2004) for identifying accessible web elements (see Section 2.2.1 for more details).

Considered contributions focus mainly on individual aspects of the complex problem we aim to solve in this research work, like characteristics of the emergency situation (i.e. CAP and the Emergency Response Ontology) or users' profiles (i.e. the AccessOnto Ontology). What is needed is a solution that could cover all identified factors: user's profile (e.g. needs, abilities, expertise and location), exceptional circumstances (e.g. stress, unknown environment, unavailable infrastructures or lack of information), available technology and response activities (e.g. evacuation procedures).

3.3 Objectives

While in the previous section we have identified our research question in making alert notifications about emergency and evacuation procedures accessible for each user, context and communication infrastructure, here we are going to detail it with a set of objectives.

1. Adapt the content of alert notifications considering three main factors:
   (a) the *user*, according to several aspects of the user's profile like abilities (e.g. contextual or functional disabilities), geographical location, age (e.g. children or elderly) and any other vulnerabilities that could help in identifying information needed for responding to the current situation;
   (b) the *situation*, seen as useful information to alert adequately the affected population. In particular, it refers to the physical condition of the environment, the characteristics of the emergency and the available evacuation procedures;
   (c) the *context of use*, as users' devices [1] and available communication infrastructures (e.g. mobile network or radio signals) for guaranteeing an effective reception of notified alerts.

[1] Notifications should be adapted to different kinds of devices depending on which the user is carrying on with her.

2. Choose the most suitable communication channel for sending alert notifications considering also here the three factors previously introduced:
   (a) features of the device employed by the *user* specifying any special tool she could need;
   (b) damages or other exceptional circumstances that could affect communication infrastructures within the current *situation*;
   (c) available communication channels depending on the specific characteristics of the *context of use*.
3. Be compliant with interoperability between systems already developed for managing emergency situations and evacuation procedures.
4. Be compliant with standards already used for emergency communications (e.g. CAP - Common Alerting Protocol).

The research question and the objectives have been identified from the analysis of the contributions considered within the application domain and the knowledge base. Both of them will be successively taken as input for the design and development of a valid solution. In particular, each objective represents a specific aspect that the solution has to satisfy, as we will demonstrate in the next chapters.

Chapter 4

Design and development of the solution

In this chapter, we propose a solution for making alert notifications accessible for every user in any context. First of all, we revisit the Design Science Research Methodology introduced in the previous chapter (see Section 3.1) adapting it to our research question, the requirements and the theoretical foundations identified from the analysis of the state of the art as inputs for the design cycle (see Figure 4.1).

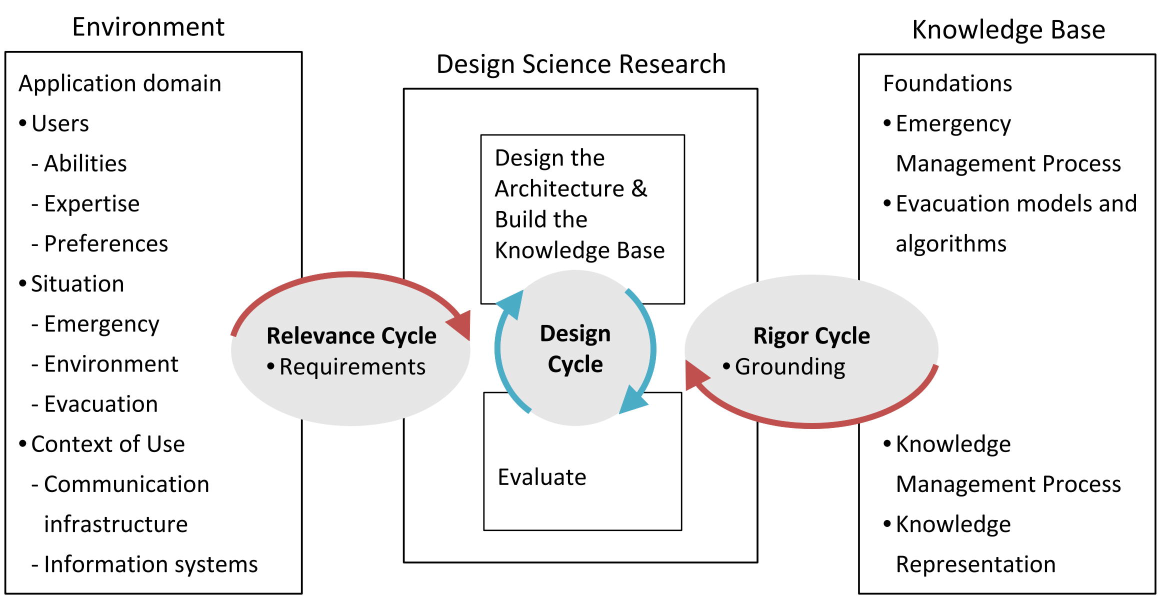


Figure 4.1: The specific Design Science Research Methodology for this thesis.

The requirements extracted from the application domain are categorized into three main factors: the users, the situation and the context of use. About the users, the design cycle has to consider the abilities (e.g. children, elderly, contextual or functional disabilities), the expertise (e.g. citizens, emergency operators) and and the preferences (e.g. age, geographical location, used device). The requirements about the situation are related to the characteristics of the emergency, the evacuation procedures and any other environmental variables that could be useful for the solution. The third factor, the context of use, gathers data about the available communication infrastructure and the existent information systems for managing information about emergencies and evacuation procedures.

4.1 Design goals

The four objectives listed in Section 3.3 of the previous chapter and the requirements previously specified are transformed into design goals to achieve within the design cycle. In Table 4.1, several design goals are presented and associated to the objectives already identified.

In order to satisfy the identified design goals, we propose an architecture with four different components that take in input three elements (see Figure 4.2). Each one of the four components have been identified and characterized during the analysis:

- The *Notification Mechanisms* are defined as part of existent emergency information systems. They take the characteristics of the *user*, the *situation* and the *context of use* as input to generate adapted alerts about emergency and evacuation procedures. In particular, the adaptation refers to the sent information and the used communication channel and it is strictly related to the three inputs.

- The *Communication Protocols* group existent protocols used for communicating and sharing information about emergencies and evacuation procedures. In this case, the protocols are sets of rules and procedures for formatting and exchanging messages among communication systems, as they are defined in (Encyclopaedia Britannica, 2013). The notification mechanisms have to take into account these protocols. In particular, the communication channel used for the notification has to be adapted considering also existent protocols.

- The *Emergency Systems* represent existent information systems that have been already developed for managing crisis situation and evacuation procedures.

Table 4.1: Relationship between the objectives and the design goals

Objective	Design Goal
1. Adaptation of the content of alert notifications considering the *user*, the *situation* and the *context of use*.	1.1. Identify most relevant characteristics of the *user*, the *situation* and the *context of use*. 1.2. Standardize such characteristics as input for the notification mechanism. 1.2. Define the content of the alerts depending on the standard inputs of the notification mechanism.
2. Adaptation of the communication channels of the alert notifications considering the *user*, the *situation* and the *context of use*.	2.1. Define the communication channels as part of the notification mechanism. 2.2. Relate the inputs already standardized (i.e the *user*, the *situation* and the *context of use*) to select an adequate communication channel.
3. Interoperability with existent information systems for emergencies and evacuation.	3.1. Define the notification mechanism as part of existent emergency information systems. 3.2. Standardize both the inputs and the outputs of the notification mechanism. 3.3. Make both the inputs and the outputs of the notification mechanism interoperable with the inputs and the outputs of existent information systems.
4. Interoperability with existent standards for emergency communications.	4.1. Standardize the communication channels. 4.2. Identify most relevant characteristics of existent communication protocols. 4.3. Make the communication channels interoperable with identified characteristics.

Considering that the notification mechanisms are part of these systems, it is crucial to guarantee their compatibility for an efficient communication of updated information.

- The *Knowledge Base* is the heart of the architecture and it is in charge of relating the other three components. The adaptation of the notification mechanisms as well as the interoperability with the existent communication protocols and the information systems are defined in this component.

In order to adapt the alert notifications and make them interoperable with existent solutions, a deep correlation among the first three components (i.e. the notification mechanisms, the communication protocols and the emergency systems)

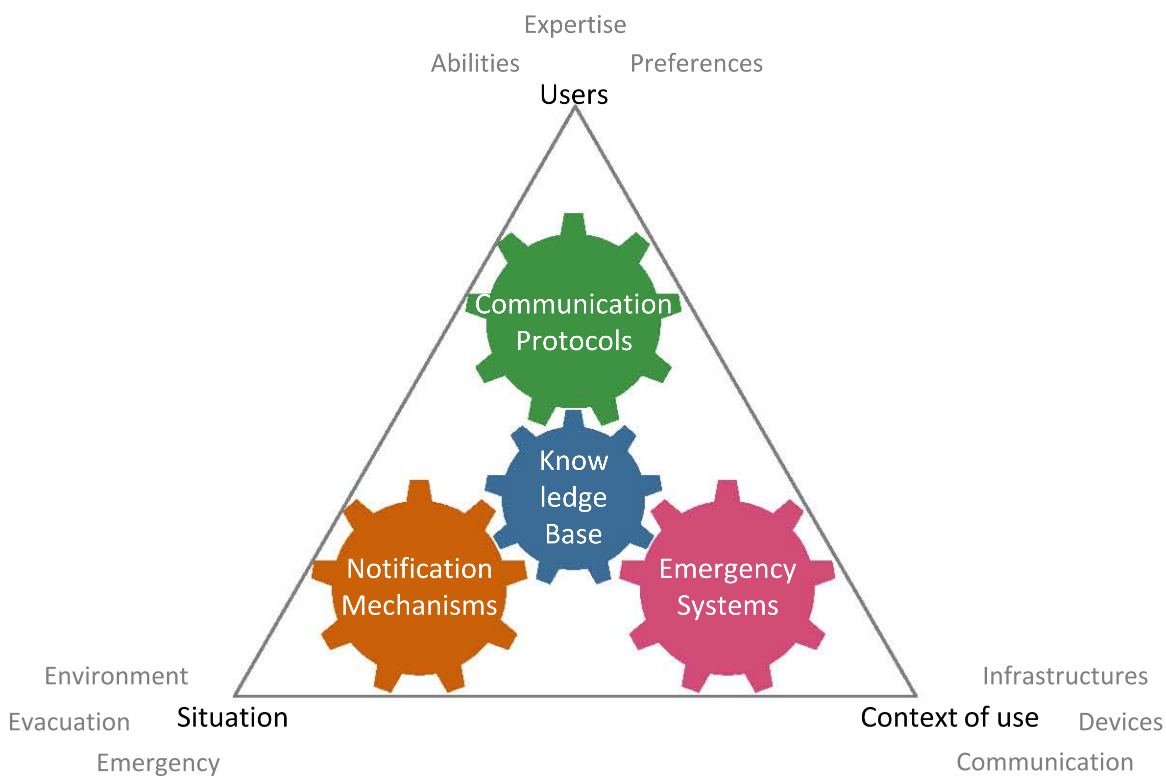


Figure 4.2: The architecture of the proposed solution.

is required. This correlation is obtained through the definition of the fourth component (i.e. knowledge base). In Figure 4.2, the entire architecture is shown: the four components are represented as gears, where three of them (i.e. the notification mechanisms, the communication protocols and the emergency systems) are connected by a common one in the center (i.e. the knowledge base).

Moreover, the four gears are included into a triangle that represents the crucial role of the three input elements: the *user*, the *situation* and the *context of use*. As required by the design goals, each one of these elements are characterized focusing on their main factors. For the *user*, the abilities (e.g. elderly, children, functional or contextual disabilities), the expertise (e.g. citizens or emergency operators) and the preferences (e.g. users' devices and geographical locations) are considered. The *situation* input concerns the environmental circumstances, the characteristics of the emergency and the evacuation procedures. The *context of use* includes the communication technologies, the available infrastructures and devices.

4.2 Design Scenarios

The proposed architecture has been designed based on the pointed out goals, as shown in the previous section. Here, we are going to design two scenarios as representation of the research question (Dix et al., 2003). The research question, already introduced in the previous chapter (see Section 3.2), can be summarized as the lack of a mechanism for adapting provided notifications to the users' needs and the context, guaranteeing also the interoperability with the available communication infrastructure and platforms. Through the description of these stories we are going to justify the proposed architecture as a valid solution for the research question.

4.2.1 The first scenario: a tornado warning

Maria lives in Oklahoma City and she has a deaf-blind disability. Her personal device is a smartphone with Internet connection with a special tool for reading the screen and converting text and images into braille. In this way, Maria can receive and send messages or access to different kinds of information. One day, the weather forecast for the Oklahoma City detects that a tornado is expected in around 6 h. For this reason, the emergency organizations in charge of managing the situation decide for a mass evacuation of the most critical areas of the city.

Following the proposed architecture (see Image 4.2), the emergency organizations alert people involved in the evacuation procedures through a notification mechanism interoperating with their emergency management system. This mechanism aims to send accessible notifications to the users' devices. In order to be notified, the users have to subscribe the service specifying any useful details about their profiles. Taking advantage of this, the notifications are adapted depending on the three input of the architecture: the user's profile, the characteristics of the tornado and the surrounding environment.

In this particular scenario, the workers manage updated data about the tornado through the emergency system while the notification mechanism uses the same information to format the alerts for subscribed users. Considering the limited abilities of Maria, she receives a text message with a map that her device converts into braille. Moreover, she cannot evacuate by herself and for this reason she is guided to a meeting point where an assistant would help her.

This first scenario is an example of how the proposed architecture can be applied for defining an automatic procedure that adapts emergency and evacuation alerts depending on users' abilities, kind of emergency and context information. In this way, we can facilitate the response activities performed by the emergency operators giving to affected people instructions to react efficiently to the crisis.

4.2.2 The second scenario: an earthquake disaster

Two colleagues, John and Tony, move to California to work. They are not familiar with this area and for this reason they decide to subscribe an emergency service to be notified in case of critical situations.

During their stay in California, an earthquake occurs and the emergency organizations receives updated information in the form of CAP messages from the Homeland Security Advisory System [2] . The response activities start when two different CAP alerts are notified:

- the first one indicates that an earthquake occurred in California, including details about the area where the situation took place;
- the second one concerns an update issued by the Department of Homeland Security where the threat level is elevated to orange (i.e. the highest level of urgency). Moreover, this alert contains several additional resources as an image, a textual description and a link to a map of affected area.

Applying the proposed architecture (see Figure 4.2), the system can access to the information included into the two CAP messages using collected data to manage the emergency process. In particular, these data are adapted and notified to people in the affected area. In case of the two colleagues John and Tony, they do not know the geography of the area and they could have difficulties in evacuating and reaching a safety point. The notification mechanism has to consider this contextual disability to adapt both the content and the visualization of sent information. For example, an augmented reality view of the evacuation route could be more helpful than a classic map, since users are not familiar with the names of the streets.

As in the previous case, also this second scenario is an example of how the proposed architecture is a solution for guaranteeing the interoperability with existent protocols and the adaptability for different users' profiles. Compared to the first scenario, it is interesting to note that in this case the adaptability concerns not only functional but also contextual disabilities. In some way, John and Tony are considered a vulnerable group by the emergency operators requiring a special attention in case of evacuation.

[2] Web site of the Advisory System by the Department of Homeland Security, http://www.dhs.gov/national-terrorism-advisory-system

4.3 Knowledge base design

Within the proposed architecture, the critical module is the *Knowledge Base* in charge of relating the other three components (i.e. *Notification Mechanisms*, *Communication Protocols* and *Emergency Systems*). As discussed in Chapter 2, in literature several Information Technology tools have been already developed as contributions for each of these three components. For instance, the Cooper Notification system is an example of *Notification Mechanism*, the CAP format is a kind of *Communication Protocol* and the Sahana Eden is an *Emergency System* (see Section 2.1.3 for more details). Otherwise, there is a lack in the correlation among each component. For this reason, in this thesis we focus on the design of the *Knowledge Base* module.

From the research question and the objectives already defined in the previous chapter (see Section 3.2 and Section 3.3), we posit that a valid solution for the *Knowledge Base* requires a deep correlation among three main factors:

- the *user*, meaning abilities, expertise and preferences already included in her profile;
- the *situation*, considering the physical condition of the environment, the predefined evacuation procedures and the characteristics of the emergency;
- the *context of use*, with current practices of use about the kind of device or infrastructure employed to communicate.

In order to establish such correlation, first we need to detail the knowledge behind each one of these factors identifying at least four *domains of interest*: accessibility, technology, emergency and evacuation. The accessibility domain includes information about the *user*, while the technology represents the *context of use* and the emergency and the evacuation detail the *situation*.

Second, the four domains of interest have to be adequately modelled and integrated into a common structure. Considering that an adequate and complete model has to deal with an articulated knowledge, we propose an Artificial Intelligence (AI) system (e.g. expert systems, neural networks, ontologies). This kind of systems are based on the definition of a set of concepts and relations as abstract representation of the entities and the properties included into the considered area of knowledge. In this particular case, the proposed solution has to deal with four different areas of knowledge already mentioned (i.e. accessibility, technology, emergency and evacuation) requiring also the identification of complex relations among them.

Among AI-based solutions available in literature, we propose the design and the development of an ontology that we will call SEMA4A (Simple Emergency Alerts 4 [for] All). This choice is strictly related to the fact that trough ontologies it is possible to conceptualize articulated knowledge including complex relations among concepts. Moreover, several tools like first order logic can be applied to verify the validity and integrity of the codified knowledge. Finally, ontologies provide a semantic resource to describe information related to a specific domain, guaranteeing in this way the interoperability with existing systems for evacuation procedures and emergency management.

4.3.1 Designing SEMA4A

The design and the development of an ontology is a complex task that requires the involvement of an expert for determining which concepts and relations have to be included. Analysing most relevant contributions for design methodologies in the area of Knowledge Management, we chose to adapt the knowledge management life cycle as it has been presented by Maier in (Maier, 2007). Maier describes eleven classes of tasks and activities to perform in order to define a consistent representation of a knowledge area.

Considering the scope of this thesis, we have adapted this knowledge management life cycle focusing on the four classes which are intended for acquiring and organizing knowledge: *Knowledge Identification*, *Knowledge Acquisition*, *Knowledge Creation* and *Knowledge Organization*. As shown in Figure 4.3, a part from the first one each step takes as input the output of the previous one until reaching the final proposal for SEMA4A.

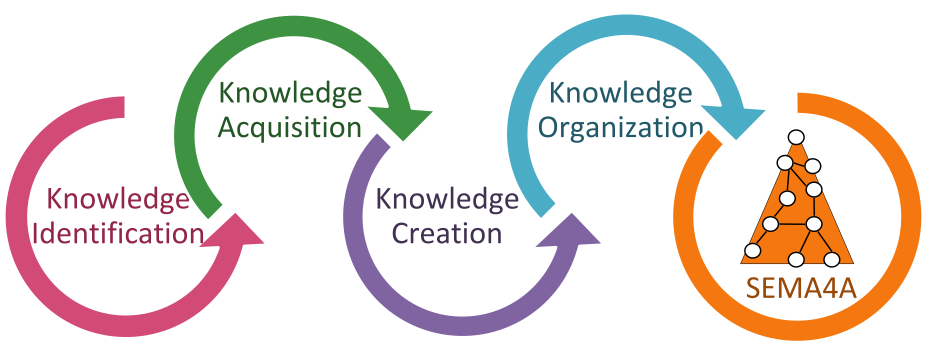


Figure 4.3: The four steps of the design process of SEMA4A, inspired by the knowledge management life cycle by Maier (Maier, 2007)

4.3.2 Knowledge identification

The first step of the applied knowledge management life cycle is the Knowledge Identification. Its aim is to identify sources for retrieving relevant knowledge about the domains of interest. In this work, we consider the four domains of interest, namely accessibility, technology, emergency and evacuation. For each of them we analyse the related state of the art looking for the most representative sources of information.

Accessibility

For accessibility, we have found several existing ontologies. Among them, we choose two of them that sufficiently cover the characterization of the *user* as a relevant factor for the personalization mechanism.

The first one is WAfA (Web Authoring for Accessibility), developed by the Information Management Group of the Computer Science Department at the University of Manchester. This ontology is also known as the Travel Ontology because it is based on the analogy of tourists' trips with web navigation. WAfA includes concepts and relations necessary to automatically model the structural organization and navigation of accessible websites (Harper and Yesilada, 2007). Moreover, the same authors have previously developed a semi-automatic tool called Dante for improving navigation between web pages for people with visual deficiencies. To do this, the tool translates the concepts of WAfA into web page elements (Yesilada et al., 2004).

The second source we have selected for accessibility is the ontology called AccessOnto developed at the Businesses School of the Canterbury Christ Church University (Masuwa-Morgan, 2008). The goal of this ontology is to extract specific requirements for accessibility. In particular, the ontology is built taking into account the users' profile and actions that they are able or not to perform. The development process uses several repositories with mainly two kinds of knowledge: declarative and procedural. The declarative knowledge focuses on a limited set of classes defined by guidelines, interface objects and users' characteristics. The procedural knowledge is composed by production rules for capturing the ideas of adaptive programming and multiple relations management (entities and dependencies). The guidelines included in AccessOnto are proposed by: WCAG, Sun Micro System, IBM, Microsoft and Apple. The main problem that occurs within the building process of AccessOnto is that considered guidelines do not use a standard format. This makes it difficult to integrate additional guidelines from different sources.

Technology and Emergency

Considering that the scope of this thesis is related to emergency notification mechanisms, for the domains of technology and emergency we are interested in sources that could represent both of them. In particular, we have found two taxonomies about media technologies and kinds of emergencies. The first one has been published by the official portal of the State of Florida (The State of Florida, 2013) and it is a simple set of words about emergencies and media technologies. The second one is *A Simple Taxonomy for Mobile Emergency Announcement Systems* by Addams-Moring et al. (Addams-Moring et al., 2005). This taxonomy collects words related to the characteristics of mobile emergency notification systems. Both of these sources have been chosen taking into account the suggestion of several emergency field experts interviewed from the Spanish Civil Protection Department.

Another source that we have considered for technology and emergency is the open standard protocol CAP (OASIS Emergency Management Technical Committee, 2010), already introduced in the Section 2.1.3. This protocol aims at standardizing information included into alert notifications about emergency situations. The related XML-schema is composed by four main elements: alert, info, resource and area with several sub-elements. Each one of them represents a specific information to communicate or share.

Evacuation

In relation to the domain of evacuation, we could not find any taxonomies or existing knowledge representations in literature. For this reason, we have collected a set of documents (i.e. corpus) specific for the domain. Such sources can be both internal and external respect to the area of knowledge. We distinguish between two different kinds of documents:

- academic and research contributions like books, papers or journals about evacuation models and simulations,
- technical reports published by official channels like evacuation guidelines, plans or procedures.

Belonging to the first category, we have found almost sixteen academic papers mainly about simulation models, optimization and other IT-based solutions for evacuation (Yusoff et al., 2008; Simonovic and Ahmad, 2005; Shekhar and Lu, 2004; Pelechano and Malkawi, 2008; Mól et al., 2008; Lu et al., 2005; Liu et al., 2005; Kirchner and Schadschneider, 2002; Kim et al., 2007; Kevin et al., 2005; Goldblatt, 2004; Gianni et al., 2008; Galea, 2004; Cova and Johnson, 2003; Chiu, 2004; Chen et al., 2006), a practitioners' forum about the hurricane Katrina and the applied evacuation procedures (Wolshon et al., 2006) and the proceedings of the International Conference on Emergency Preparedness entitled *The Challenges of mass Evacuation* (Various Authors, 2010).

In the second category, we have collected about thirty evacuation plans implemented for universities and city halls and sixty general evacuation procedures, guidelines and standards published by different official entities (i.e. Security Departments of university, city halls and companies, like the federal agency OSHA - Occupational Safety and Health Administration).

4.3.3 Knowledge acquisition

This step is aimed at acquiring information from the sources that have been identified during the previous step. The tasks to perform for acquiring most relevant knowledge depends on the characteristics of such sources.

Accessibility

Starting from the domain of accessibility, the selected sources are already structured as ontologies (i.e. WAfA and AccessOnto). This means that the included concepts and relations can be reused within SEMA4A. In this case, the main efforts are concerned with the integration among them and the knowledge acquired from the other domains, as shown in the next step (i.e. Knowledge creation).

Technology and Emergency

In the case of technology and emergency, the identified sources are two taxonomies and a XML-schema composed by several elements and sub-elements. From them, we have extracted an initial list of terms that are relevant for these domains. The list is very poor due to the nature of the selected sources. For this reason, it has been successively enriched and refined with additional concepts in order to cover adequately the considered areas of knowledge. To do this, we apply a semi-automatic procedure to define new concepts and relations using the language ontology WordNet (Miller et al., 1990). WordNet is a sort of English dictionary with nouns, verbs, adjectives and adverbs. For each one of them, several *synsets* are defined, where a *synset* is a group of synonyms associated to a different meaning for the specific word. Additional semantic relations are identified (e.g. hypernym, hyponym and holonym) creating an interlinked network of concepts.

In Figure 4.4, the diagram of this step is shown. The starting point of the applied procedure is the initial list of terms (the *Term Candidates* in Figure 4.4) obtained from the sources previously identified ((The State of Florida, 2013), (Addams-Moring et al., 2005), (OASIS Emergency Management Technical Committee, 2010)). We proceed retrieving these terms in WordNet and for each one of them we collect the associated *synsets* and semantic relations (the triple <*Term, Semantic Relations, Synsets*> in Figure 4.4).

We iterate this procedure for each synonym included into the *synset* (the *Synonyms* in Figure 4.4) until a maximum of three levels. This threshold has been experimentally set considering that fewer levels generate few terms, while more levels added terms which are not really related to the domains of interest. The synonyms included into the collected *synsets* are acquired enriching the initial list of terms, while the semantic relations will be used in the next step for interlinking them.

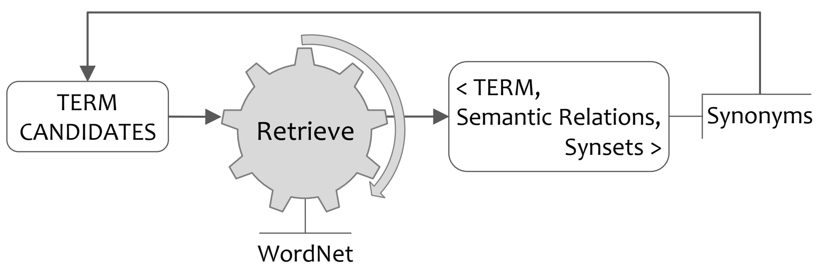


Figure 4.4: The Knowledge Acquisition step for Technology and Emergency

Evacuation

The knowledge acquisition for the domain of evacuation has three different phases, as shown in Figure 4.5. The first phase is the *parsing* that applies a natural language processing technique for extracting representative terms for the domain of evacuation from the *corpus* of documents previously acquired as source. This technique initially tags each word in the textual documents with its semantic function (e.g. nouns, verbs and adjectives). The tagging is performed using the Part-Of-Speech Tagger (POS Tagger) developed by Toutanova et al. from the Stanford natural Language Processing Group in the Stanford University (Toutanova and Manning, 2000). Once the entire corpus has been tagged (the *Tagged Corpus* in Figure 4.5), the *extracting* phase retrieves a list of about 5.250 nouns in their root form (the *Term Candidates* in Figure 4.5). These nouns are the candidate terms to be part of the knowledge representation. As candidates, they have to be filtered out during the last phase (*filtering*) in order to select just most representative ones (the *Evacuation Concepts* in Figure 4.5).

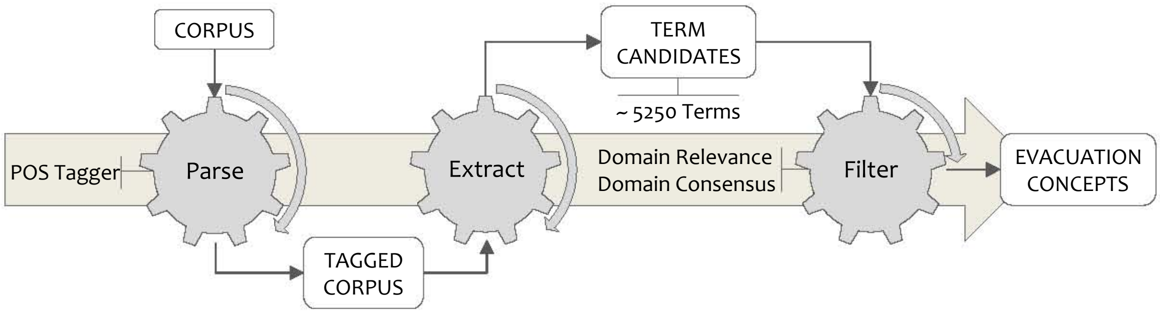


Figure 4.5: The Knowledge Acquisition step for Evacuation

The filtering uses two semantic functions, **Domain Relevance** (DR) and **Domain Consensus** (DC), defined by Navigli et al. in (Navigli et al., 2003).

The **Domain Relevance** aims to evaluate the specificity of a term for a particular domain (i.e. domain of interest) contrasting with other domains of knowledge (i.e. domains of contrast). In order to achieve it, it computes the frequency of each candidate term over the domain of interest and compares it with the frequency computed over the domains of contrast. In our case, analysing the collected corpus of documents we have recognized the use of concepts from the areas of civil engineering, architecture and emergency for describing buildings, locations, critical events and risks. For this reason, we chose them as domains of contrast.

To compute the frequencies of each candidate term in the domains of contrast, we need to associate them with a representative corpus of documents. For the civil engineering and architecture domains, we have collected several handbooks from GoogleBooks (Google, 2013). For the emergency domain, we have collected several academic papers from the proceedings of the conference ISCRAM 2007 (Intelligent Systems for Crisis Management) (Various Authors, 2007), a manual developed by the North Central Texas regional government (North Central Texas Regional Government, 2013) and papers about the role of communities within the emergency management process ((Schafer et al., 2008), (Schafer et al., 2007), (Van De Walle and Turoff, 2007), (Carver and Turoff, 2007), (Turoff, 2002), (Turoff et al., 2004)).

Given the four domains labelled D_1 for evacuation, D_2 for civil engineering, D_3 for architecture and D_4 for emergency, the Domain Relevance of a term t in D_1 is formally defined as

$$DR_{t,D_1} = \frac{P(t|D_1)}{\sum_{j=1}^{4} P(t|D_j)'},$$

where $P(t|D_k) = \frac{f_{t,k}}{\sum_{t' \in D_k} f_{t',k}}$ with $k \in \{1, 2, 3, 4\}$.

This function compares the probabilities that a term is frequent over the three domains of contrast with the frequency in the domain of interest. Consequently, a high Domain Relevance means that the term is mostly significant for the domain of interest D_1.

The **Domain Consensus** is based on the idea that a term is relevant for a domain if it is highly frequent in each document of the corpus. Consequently, it computes and successively combines the frequency of each term in each document through the entropy function H. In Information Theory, the entropy is a measure of the uncertainty of a variable: a low value for entropy means that the information received about the variable is enough to clearly identified it (Ihara, 1993). In case of Domain Consensus, the variable is the candidate term and the information about the variable is represented by the documents in the corpus. Consequently, the uncertainty of the candidate term depends on how much the documents use it (i.e. it is frequent in the documents). As a result, a low value of the Domain Consensus (i.e. a low entropy) means that the term is frequent over the whole corpus.

Given the domain of evacuation labelled D_1, the Domain Consensus of a term t over the documents d of the corpus is formally defined as

$$DC_{t,D_1} = H(P(t, d)),$$

where $H(P(t, d)) = \sum_{d \in D_1} P(t|d) \log \frac{1}{P(t|d)}$ and $P(t|d) = \frac{f_{t,d}}{\sum_{d \in D_1} f_{t,d}}$.

Once the Domain Relevance and the Domain Consensus have been computed, the relevance of candidate terms is determined combining both functions in the term weight TW formally defined as

$$TW_{t,D_1} = \alpha DR_{t,1} + (1 - \alpha) DC_{t,1},$$

where the parameter α is included in the range $[0, 1]$. The value of α has been determined experimentally as 0,75 looking at the obtained list of terms and verifying their relevance for that domain.

4.3.4 Knowledge creation

In the third step, called Knowledge Creation, tasks for creating knowledge already acquired are carried out. The creation phase is a complex process for learning about the domain of interest. This process involves both individual and collective activities. In particular, the collaboration among domain experts plays a crucial role for identifying most representative terms and relations. If needed, it is supported by facilities such as special rooms for enhancing the interaction and the discussion of ideas.

In this research work, the creation consists of correlating the lists of terms already acquired from the four domains of interest (i.e. accessibility, technology, emergency and evacuation) defining ad-hoc relations. To do this, we apply different approaches depending on the characteristics of considered domains. We are going to start with accessibility, integrating successively technology and emergency and finally evacuation.

Concerning the domain of accessibility, first of all we combine the two ontologies selected as sources during the Knowledge Identification step (i.e. WAfA and AccessOnto). To do this, any possible semantic links among included entities are identified, avoiding any possible redundancies.

After that, we integrate the technology and emergency terms using the three semantic relations extracted from WordNet (Miller et al., 1990) (i.e. hypernym, hyponym and holonym as defined in Table 4.2) during the Knowledge Acquisition step. These relations correlate technology and emergency with accessibility, mapping the terms belonging to each one of them.

Table 4.2: Examples of the identified semantic relations from WordNet

Semantic Relation	Example
Hypernym, *term1* is kind of *term2*	*hurricane* is a hypernym of *cyclone*
Hyponym, *term1* is general of *term2*	*terrorism* is a hyponym of *bioterrorism*
Holonym, *term1* is part of *term2*	*fire-eater* is a holonym of *fire department*

Finally, we link the knowledge acquired for evacuation. To do this, we use a natural language processing technique. This technique uses the same corpus of documents collected during the Knowledge Identification and tagged by the POS Tagger during the Knowledge Acquisition. From the tagged corpus, the employed technique consists of extracting triples composed by two nouns and a verb in their root forms. These triples represent possible candidates for the mapping: the two nouns are terms already acquired for the domains of interest and the verb is the relation among them. In this way, we obtain 20.161 candidate triples, successively filtered manually looking for any inconsistencies or redundancies taking into account the relations already included in the knowledge representation.

4.3.5 Knowledge organization

After the Knowledge Creation, in this last step the final structure of the knowledge representation is defined and implemented. As already introduced, within the scope of this thesis the chosen knowledge representation is an ontology called SEMA4A. Considering that the main goal of SEMA4A is to correlate four different domains (i.e. accessibility, technology, emergency and evacuation), the proposed structure consists of the following four general classes (see Figure 4.6):

- *Accessibility* representing the accessibility guidelines, users' profiles, users' abilities and accessible contents for users;
- *Communication* representing the communication infrastructures, media and channels;
- *Emergency* representing the characteristics of emergency situations and the kinds of emergencies;
- *Evacuation* representing the evacuation procedures and processes.

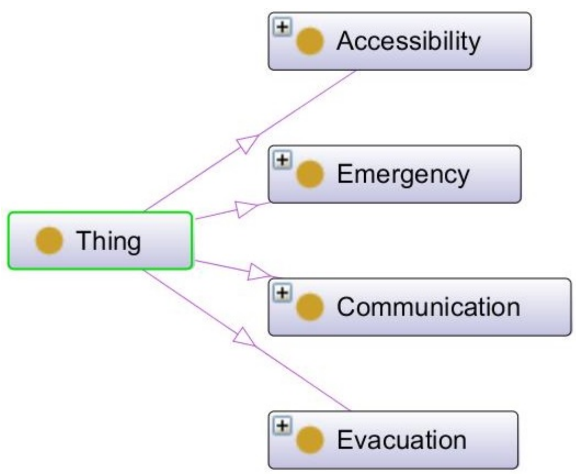


Figure 4.6: The main structure of SEMA4A

In Figure 4.6, the main structure of SEMA4A is shown. The *Thing* class is the root of the entire hierarchy and it is an abstract object considered as the super-class of the remaining elements of the ontology. The correlation among all the terms included into SEMA4A is guaranteed by the relations that have been identified during the Knowledge Creation step.

The *Accessibility* class

The *Accessibility* class collects the terms extracted during the Knowledge Acquisition from the two sources WAfA and AccessOnto and successively integrated during the Knowledge Creation. It is organized into three subclasses (see Figure 4.7):

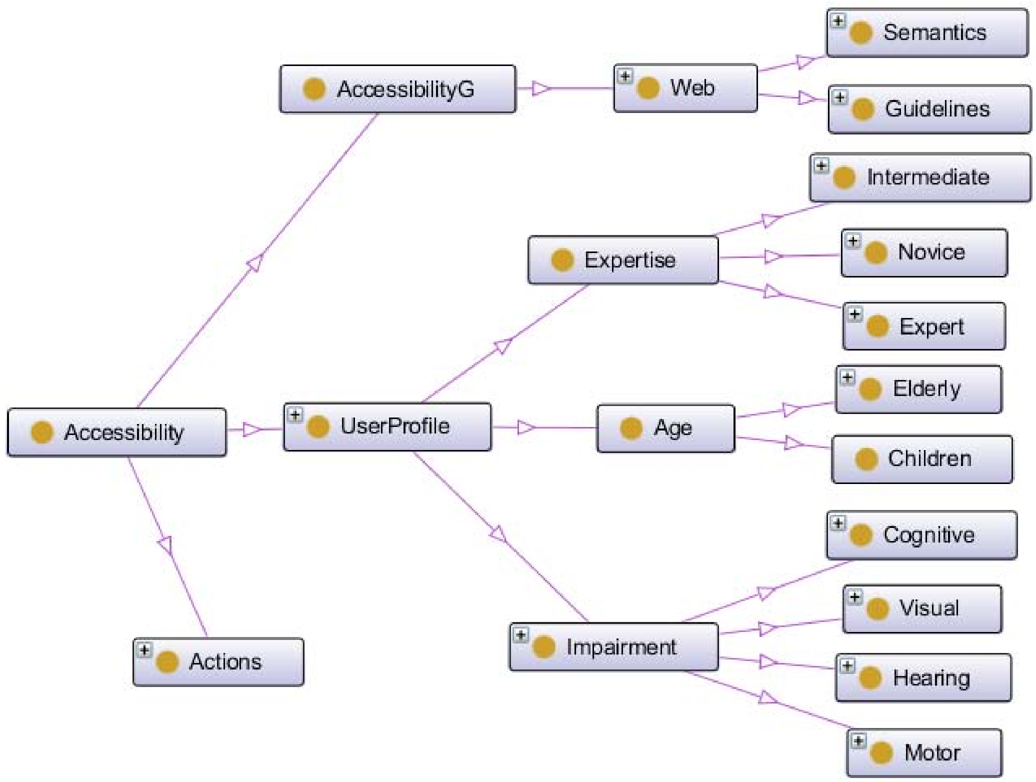


Figure 4.7: The main structure of the *Accessibility* class

- The *AccessibilityG* class includes knowledge about accessibility guidelines, structured into several levels of subclasses. The first level is the *Web* class with two children:
  - the *Semantics* class with terms about the used semantics for the guidelines;
  - the *Guidelines* class with the accessibility standards categorized by the developers (i.e. *Custom*, *IBM*, *Neuman* and *WAI*).
- The *UserProfile* class represents the characteristics and the abilities of the users' profile. Also in this case, we have define several levels of subclasses. The first level has three children:
  - the *Expertise* class includes all kind of disabilities originated by the level of technical education users have an it is subdivided into *Intermediate*, *Novice* and *Expert*;

  - the *Age* class includes characteristics and abilities strictly related to the time and it is subdivided into *Children* and *Elderly*;
  - the *Impairment* class includes all the abilities that a person can or cannot have. It is organized into four subclasses:
    * *Motor* (e.g. coordination difficulty, reach limitations, no tactile sensation);
    * *Visual* (e.g. color blindness dichromatic and color tones, low vision, blindness, deafblind);
    * *Cognitive* (e.g. word and spatial dyslexia, learning difficulty);
    * *Hearing* (e.g. deafness, deafblind).
  - the *Actions* class combines all the terms that represent relevant actions a person can or cannot perform in relation to her abilities (e.g. hearing, sense of direction, orientating, using mouse).

The *Communication* class

The *Communication* class represents the knowledge about the alert communications that has been collected and successively defined during the Knowledge Acquisition and the Knowledge Creation. In this class, we gather representative terms for the domain of technology, including also the part of the WAfA ontology related to the structure of the web page content. Moreover, it has five subclasses (see Figure 4.8):

- the *Contents* class has been imported from the WAfA ontology and it collects terms related to the structure of the web page content. It is organized into three children:
  - the *Atom* class represents the atomic elements of a text, like figures, labels, titles or captions;
  - the *Chunk* class includes objects as groups of atomic elements, like the footer or header section;
  - the *Node* class is strictly related to the DTD (Document Type Definition) of a web page.
- the *Media* class collects terms related to the communication infrastructures and channels, such as fax, newspaper, pager or radio;
- the *Devices* class is composed by the different kinds of devices, in particular mobile devices, that users can use to receive the notifications;

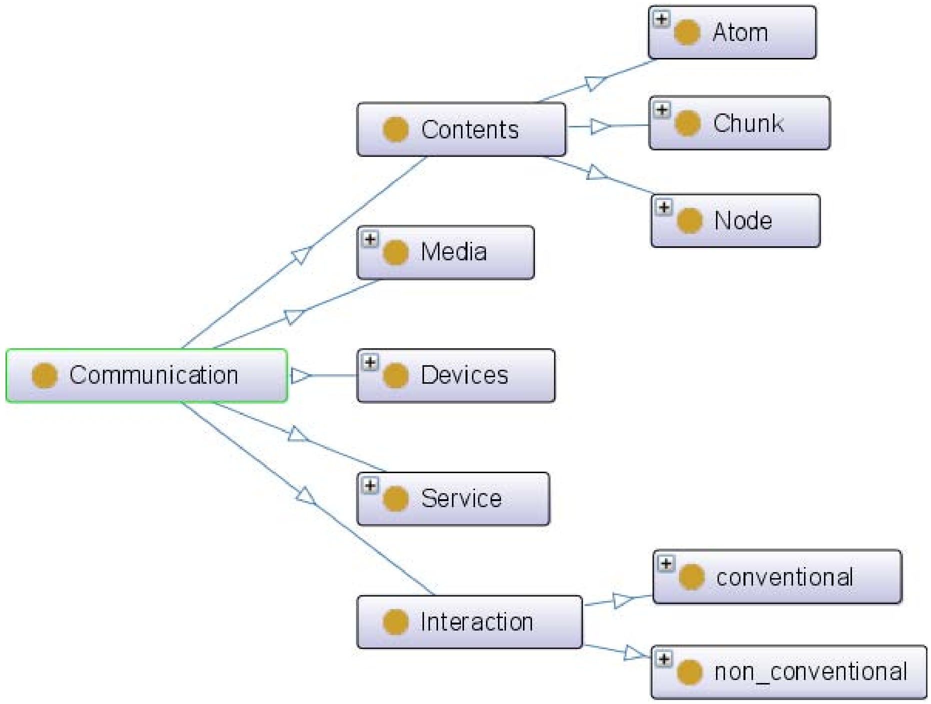


Figure 4.8: The main structure of the *Communication* class

- the *Service* class includes several ways to send messages, like e-mail, SMS or MMS;
- the *Interaction* class represents how a person can interact with a device distinguishing between *conventional* and *non_conventional* interaction. An example of *conventional* devices is the keyboard, while a *non_conventional* device is the eye tracker or the text-to-speech tool.

The *Emergency* class

The terms about emergency as they have been extracted, enriched and refined during the previous steps are part of the *Emergency* class. It represents the characteristics that a critical situation can present and the kinds of alerts to consider for an efficient notification mechanism. For this reason, it has two subclasses (see Figure 4.9):

- the *AlertType* class has been organized following the XML schema of the CAP protocol. In particular, it includes the three characteristics described in the *info* element of the protocol (see Section 2.1.3):

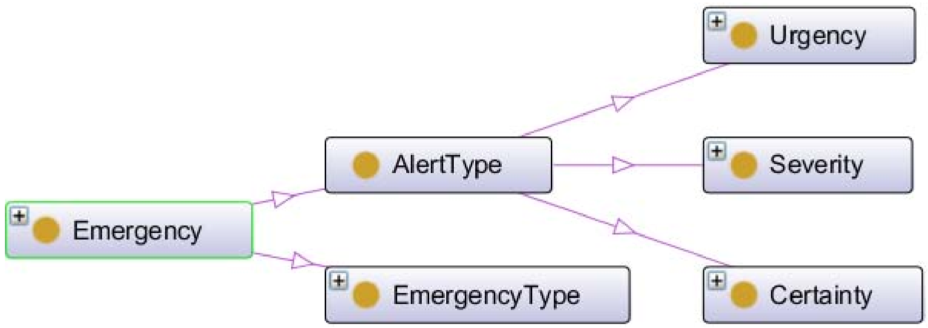


Figure 4.9: The main structure of the *Emergency* class

  - the *Urgency* class refers to the time needed for an efficient response to the crisis;
  - the *Severity* class concerns the impact of the crisis on the society and the surrounding environment;
  - the *Certainty* class represents the reliability of the received alert.

- the *EmergencyType* class represents the kinds of critical events that could affect an area. Several synonyms used for the same event are also included (e.g. tornado and twister).

The *Evacuation* class

The *Evacuation* class structured the terms defined from the scratch about the evacuation procedures, standards and models. During the entire design process, we have noticed that the domain of evacuation is strictly related to other domains, like architecture and civil engineering. As consequence of this idea, the *Evacuation* class has been organized into four subclasses (see Figure 4.10):

- the *Location* class concerns all data we have collected about the physical context in which an evacuation procedure is defined (e.g. stairs, building, elevator);

- the *Personnel* class represents the people involved in the evacuation, focusing in particular on their role (e.g. supervisor, tourist, employer);

- the *Procedure* class includes technical terms about standard procedures or plans (e.g. instruction, kit, point);

- the *Transportation* class is related to the different means that can be necessary during an evacuation for escaping (e.g. bus, car, congestion).

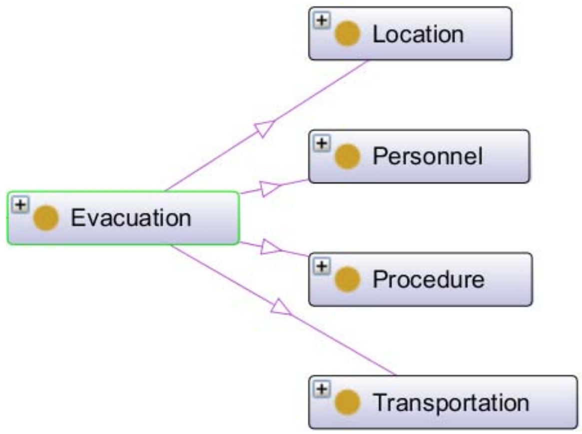


Figure 4.10: The main structure of the *Evacuation* class

4.4 Implementing SEMA4A

Once the proposed solution SEMA4A has been designed, another crucial activity for guaranteeing its efficiency and effectiveness is the implementation. Coming back to pointed out objectives (see Section 3.3), here we focus in particular on making the SEMA4A ontology interoperable with existing systems and platforms. To do this, a standard and platform independent language is needed. The one that presents these characteristics is the Web Ontology Language (OWL).

OWL is an XML-based standard developed by the World Wide Web Consortium (W3C) and become a W3C Recommendation in 2004 (World Wide Web Consortium (W3C), 2013a). OWL is not the first language defined by the W3C in the area of Semantic Web. It is an extension of two previous standards: the Resource Description Framework (RDF) and the RDF schema. In this way, the W3C aims to guarantee the interoperability of OWL with existing tools and systems based on RDF.

Within KR techniques (see Section 2.2), the OWL standard is based on a particular family of logics called *description logic*. The description logic allows to model concepts, roles, individuals and relationships among them. These elements are also traduced in the OWL standard: the concepts are defined as *classes*, the roles as *properties* of the classes and the individuals as *instances* of the classes (i.e. the leaves of the hierarchy without children). Moreover, based on the description logic roles several reasoning tools have been developed for verifying the consistency and the coherency of the OWL representation (Motik et al., 2009).

In this thesis, the classes and the relations introduced in the previous section have been codified following the OWL specifications. In particular, for each class a formal definition, properties and relationships are required. The formal definition has been extracted from the language ontology WordNet (Miller et al., 1990). The properties are the relations that we have identified during the Knowledge Creation step (both from WordNet and from a semi-automatic natural language processing), while the relationships are the ones already defined by OWL.

As an example, if we want to relate the *Urgency* class with the more general *AlertType* class, we can use the RDF schema relationship *subClassOf* in the following way:

```
<owl:Class rdf:about="#Urgency">
       <rdfs:subClassOf rdf:resource="#AlertType"/>
</owl:Class>
```

If we want to code the relation *mayHaveDifficulty* that we have defined among the *Elderly* class and the *hearing* instance, we can define an ad-hoc property. One way to do this is representing the relation *mayHaveDifficulty* as an anonymous class called *Restriction*, subclass of the first term of the relation (i.e. the *Elderly* class) and value from the second term (i.e. the *hearing* instance):

```
<owl:Class rdf:about="#Elderly">
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty rdf:resource="#mayHaveDifficulty"/>
                <owl:someValuesFrom rdf:resource="#hearing"/>
            </owl:Restriction>
        </rdfs:subClassOf>
</owl:Class>
```

As support for the implementation and the successive management of the SEMA4A ontology, we use Protégé (Stanford Center for Biomedical Informatics Research (Stanford University School of Medicine), 2013), an open source ontology editor extensively used as support for developing knowledge base. In particular, this platform offers several additional tools for visualizing, modifying and querying the ontology. For example, the graphs included in the previous section (Figures 4.6, 4.7, 4.8, 4.9 and 4.10) have been made using the OntoGraf add-on (Falconer, 2010). The OntoGraf tool allows a visual navigation through the classes, relations and instances offering several layouts and filters.

4.5 Using SEMA4A

In this section, we describe how the SEMA4A ontology can be used for solving the two design scenarios previously described as representation of the research question (see Section 4.2).

4.5.1 The tornado warning

The first design scenario concerns Maria, a deaf-blind person that lives in Oklahoma City where a tornado is expected in around 6 h and an evacuation is required (see Section 4.2.1). She has a smartphone with Internet connection and a tool for translating the content of the screen (both texts and figures) into braille. Moreover, she is subscribed to a notification service for receiving personalized alerts about emergency situations in her area. Through this service, the organization in charge of managing the evacuation procedures can alert Maria sending useful information about the incoming tornado taking into account her particular needs.

In order to personalize the alerts considering the particular situation and the Maria's profile, the notification mechanism queries the SEMA4A ontology as follows:

- From the ontology, we have that *DeafBlind* is a *Visual* and *Hearing* impairment where people cannot hear or see either partially or totally. Moreover, people with this disability may have difficulties *using a mouse*, while they may use some kinds of *speech input* or *speech output* tools, including *tactile* and *braille* ones. It is also obtained from our ontology that *DeafBlind* people can use *keyboards* and can notice *vibrations*. In Figure 4.11, the conceptualization of *DeafBlind* in the SEMA4A ontology is shown.

- Considering that *DeafBlind* people use a smartphone with *internet* access, the notification mechanism obtains from our ontology the characterization of such device. In particular, the smartphone is represented as a personal digital assistant (*PDA*) and it can communicate information contained in *figures*, *sounds*, *text*, as well as *vibration* signals (see Figure 4.12). From our ontology, it is also obtained that the approaching *tornado* is an emergency that can be communicated using *internet*, *TV* and *radio* as media channels (see Figure 4.13). Moreover, SEMA4A defines that the alert must be notified following a specific structure inspired by the Common Alerting Protocol (CAP) (see *AlertType* in Figure 4.13).

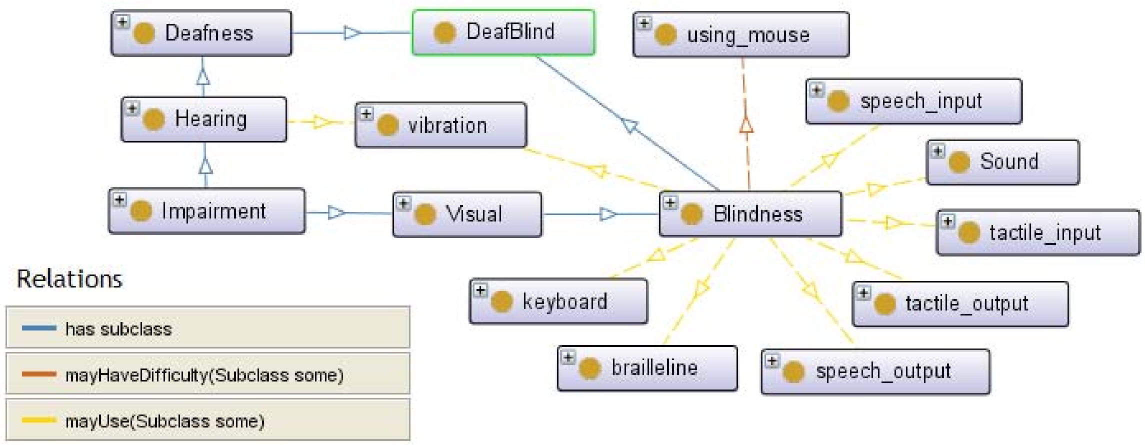


Figure 4.11: The definition of *DeafBlind* obtained from the SEMA4A ontology

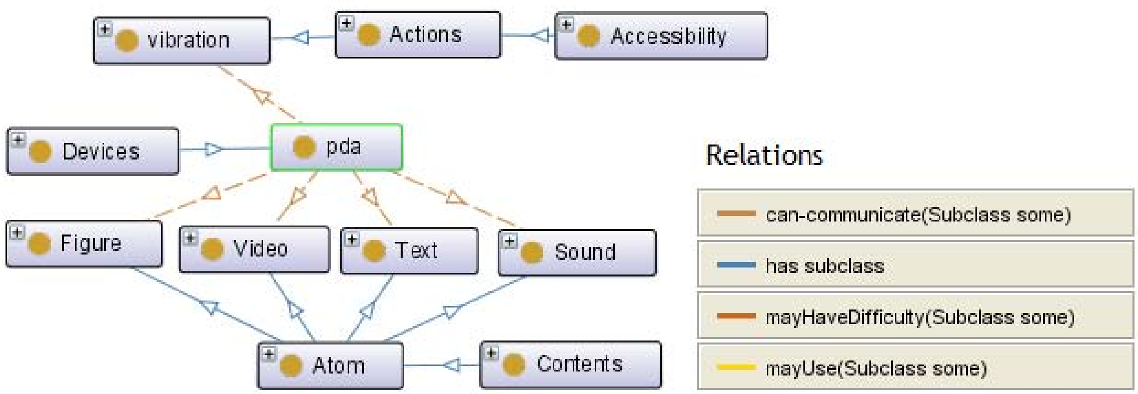


Figure 4.12: The conceptualization of *PDA* obtained from the SEMA4A ontology

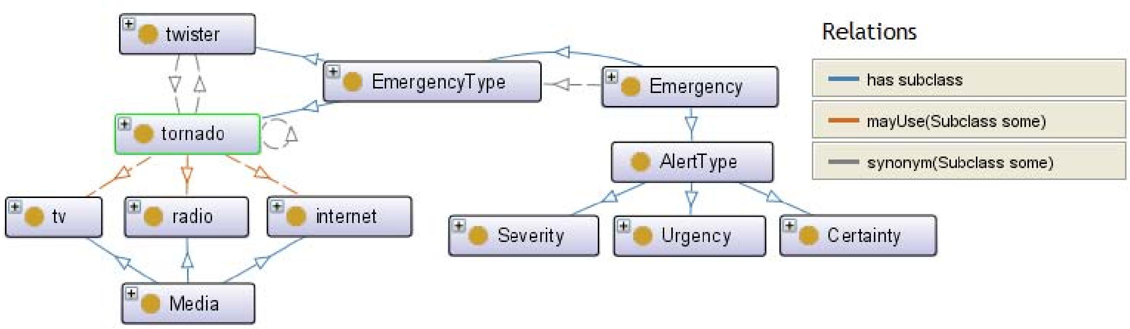


Figure 4.13: The conceptualization of *tornado* obtained from the SEMA4A ontology

- According to the profile and preferences of Maria, it is desired that the alert is notified via internet. Having this in mind, from the ontology we know that using *internet* we can communicate employing *multiple languages*, *text*, *figure*, *video*, *sound* or *emails*, as shown in Figure 4.14.

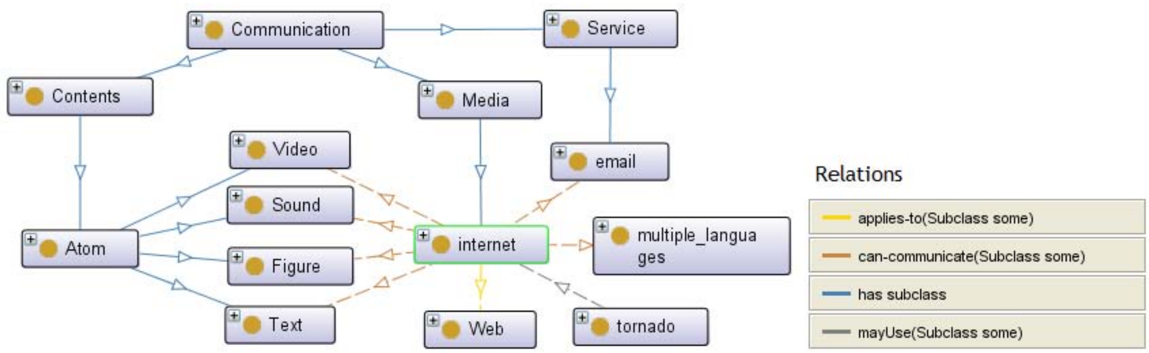


Figure 4.14: The conceptualization of *internet* obtained from the SEMA4A ontology

- In order to ensure that this person can access the information, SEMA4A infers Web accessibility guidelines specific for *DeafBlind*, as well as specific Web elements (e.g. figures or images, sounds, input controls) that need to be formatted or transformed for assuring their accessibility (see Figure 4.15). For instance, the guideline called *WCAG_1.1* suggests to associate text descriptions to the multimedia content making it readable for special tools as braille displays (World Wide Web Consortium (W3C), 2013b). In particular, this guideline is applied to the *figures* in the notification.

Following the results inferred from SEMA4A, Maria would receive a map associated to a textual description that her device converts into braille.

4.5.2 The earthquake disaster

The second design scenario concerns John and Tony, two colleagues that move to California to work. They are subscribed to an emergency service to be alerted in case of emergencies. Therefore, when an earthquake occurs the service alerts them suggesting to evacuate the area as soon as possible. The notified alerts as well as the evacuation instructions have to be adapted to the users' needs and their particular situation.

To do this, the SEMA4A ontology is queried as follows:

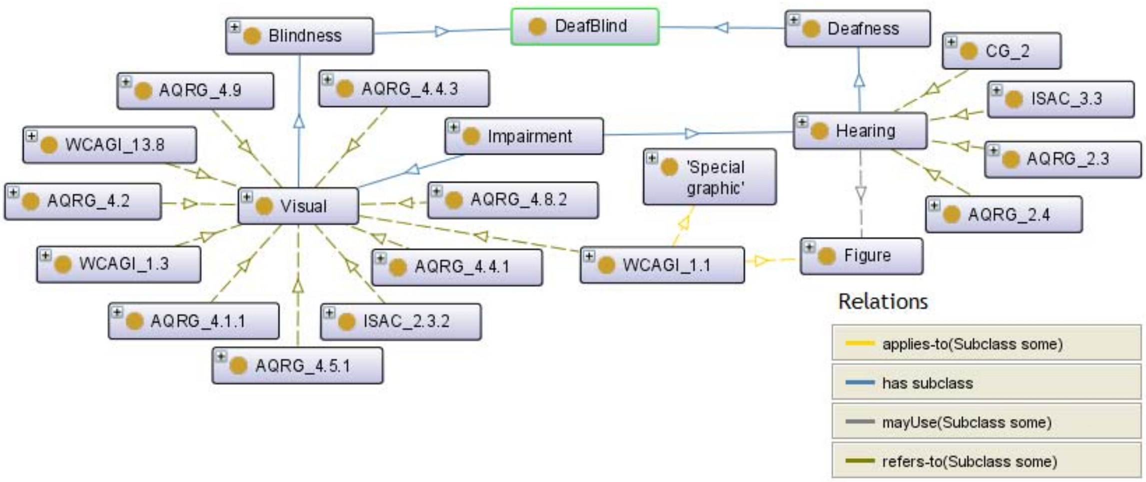


Figure 4.15: The conceptualization of the Web accessibility guidelines for *DeafBlind* obtained from the SEMA4A ontology

- Since John and Tony are not familiar with the area where they are, they are considered as a vulnerable group with a contextual disability. This is represented as a *Novice* level of *Expertise* having difficulties in *navigating* the map of the city and *orientating* themselves with almost no *sense of direction*. It is also obtained from our ontology that people with *Novice Expertise* may use a *non conventional interaction* tool, such as the *zoom* for the *map* and the *augmented reality* view for the evacuation route. In Figure 4.16, the conceptualization of the *Novice Expertise* in the SEMA4A ontology is shown.

- In order to ensure that this person can find the notified information useful for escaping and reaching a safety point, SEMA4A infers Web accessibility guidelines specific for the *Novice Expertise* (see Figure 4.17). The queried guidelines have been collected from the AccessOnto ontology (Masuwa-Morgan, 2008). They refers to an effective and minimalist learning process (*CG_24* and *CG_25*) and a minimum number of steps to perform for completing the tasks and making decisions (*CG_26*).

Taking into account these queries, John and Tony would receive a short but effective description of the steps to follow for escaping safely and a map of the route with an augmented reality view.

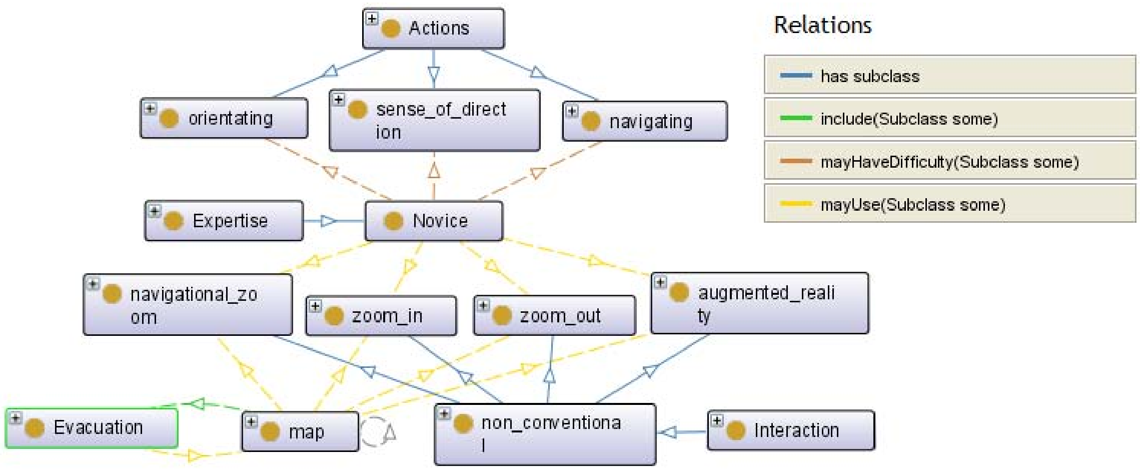


Figure 4.16: The conceptualization of *Novice Expertise* obtained from the SEMA4A ontology

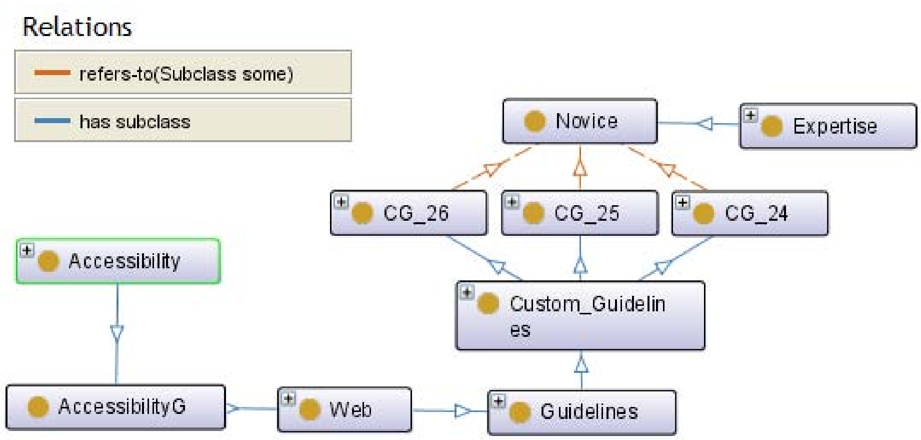


Figure 4.17: The conceptualization of the Web accessibility guidelines for *Novice Expertise* obtained from the SEMA4A ontology

Chapter 5

Evaluation

Following the Design Science Research Methodology introduced previously (see Section 3.1), the design cycle iterates between two phases (see Figure 4.1 in the previous chapter): building the solution and evaluating it. While in the previous chapter we have described the first one, here we are going to introduce the evaluation phase. The evaluation phase aims to demonstrate that the objectives pointed out in Section 3.3 have been satisfied. To do this, these objectives have to be transformed into a list of properties that the proposed architecture has to achieve.

Within the proposed architecture, the critical module is the *Knowledge Base*, in charge of adapting the notification mechanisms and guaranteeing the interoperability with the other components (i.e. the *Notification Mechanisms*, the *Communication Protocols* and the *Emergency Systems*). For this reason, we can state that the *Knowledge Base* module should have the following properties:

1. consistent and complete to guarantee an adequate representation of the user, the situation and the context of use, as they have been already characterized;
2. understandable to be applied for adapting alert notifications to the user, the situation and the context of use;
3. interoperable with other systems.

Once the desired properties have been specified, it is crucial to understand how to verify them. Considering that the *Knowledge Base* has been designed as an ontology, we have to interpret them in the context of ontology engineering. As introduced in Section 2.2, an ontology is a conceptualization of knowledge in terms of the definition of several concepts and relations between pairs of them. Consequently, in order to evaluate its quality we apply the criteria defined for the data quality of a knowledge representation, as listed in (Maier, 2007). Keeping in mind these criteria, the three properties are interpreted as follows:

1. The first property concerns the *consistency* and the *completeness* of the ontology.
   (a) The *consistency* refers to the avoidance of redundancies and misunderstandings in the definition of relevant terms and relations, as it has been introduced by Tarski in (Tarski, 1941).
   (b) The *completeness* of a knowledge model can be interpreted as a cover in depth of a broad domain of information. In (Gómez-Pérez, 2004), the author states that the completeness of an ontology depends on the completeness of each concept included in it.
2. The second property concerns the *understandability* of the given knowledge representation by the ontology. It is about how much a knowledge representation is comprehensible for human beings.
3. The third property concerns the *interoperability* of the ontology with other solutions. In particular, it is related to the ability to share and coordinate information.

In the next subsections we are going to evaluate each one of them, starting from the completeness and the understandability, following with the consistency and finally the interoperability.

From the analysis of well-known evaluation methods for ontologies, we decided to compute three functions called coverage, accuracy and precision as measures of the *completeness* and the *understandability* of SEMA4A, as they have been defined by Spyns and Reinberger in (Spyns and Reinberger, 2005) and Guarino in (Guarino, 2004). Specifically, the coverage represents how many relations defined in the ontology are representative for considered domains. Besides, the accuracy indicates the specificity of the retrieved concepts. Finally, the precision refers to their relevance.

Considering that the *consistency* and the *interoperability* are related to the syntax of the representation, the way to measure them depends on the used language for implementing the ontology. In this case, we have used OWL (i.e. the Ontological Web Language already introduced in Section 4.4). Consequently, the evaluation of the *consistency* employs an ad-hoc reasoning tool, while for the *interoperability* we have taken into account a set of principles published by the W3C (i.e. World Wide Web Consortium).

Finally, considering that the creation of an ontology is a complex process that requires the participation of experts in the domains of interest, it is crucial to involve their expertise in a qualitative evaluation. For this reason, as suggested by several authors in literature (e.g. (Gangemi et al., 2006),(Navigli et al., 2004)), the identified measures are computed following a two step methodology with a quantitative and a qualitative evaluation.

5.1 Quantitative Evaluation

For the quantitative evaluation of precision, coverage and accuracy, we are going to apply an approach inspired by the EvaLexon technique of Spyns et al. (Spyns and Reinberger, 2005). This technique is based on the extraction of a set of triples (i.e. lexons) from the ontology. Formally, a lexon is a 5-tuple:

$$<(G, L) : term1\ role\ coRole\ term2>,$$

where G is the context, L is the language, $role$ is the relation for the co-occurrence between the two terms $term1$ and $term2$ and $coRole$ is the inverse of the $role$. Nevertheless, we can omit the (G, L) pair and describe a lexon as a 4-tuple:

$$<term1\ role\ coRole\ term2>.$$

Usually only the $role$ is explicitly represented, while the inverse is implicit. Thus, a lexon is described as a triple and it can be represented in different ways, as for example with an OWL triple (where OWL is the Ontological Web Language already introduced in Section 4.4) or as a conceptual graph style relation (Sowa, 1984).

Informally, the terms in a lexon are noun phrases that carry important information about considered domains, while the relation is a verb that imposes restrictions on the meaning of the terms. For example, in the sentence *the director directs the film*, the lexon is composed by the following elements: $director$ as $term1$, $directs$ as $role$ and $film$ as $term2$.

Based on the EvaLexon technique, we have defined the three step process shown in Figure 5.1.

A In the step A, we use a tagging procedure that parse a set of documents called *corpus* associating each word with its syntactic function (i.e. nouns, verbs, adjectives, etc.) to obtain a *tagged corpus*. The tagging is performed as shown in Section 4.3.3 for acquiring knowledge from the domain of evacuation with the Part-Of-Speech Tagger (POS Tagger) developed by Toutanova et al. from the Stanford Natural Language Processing Group in the Stanford University (Toutanova and Manning, 2000).

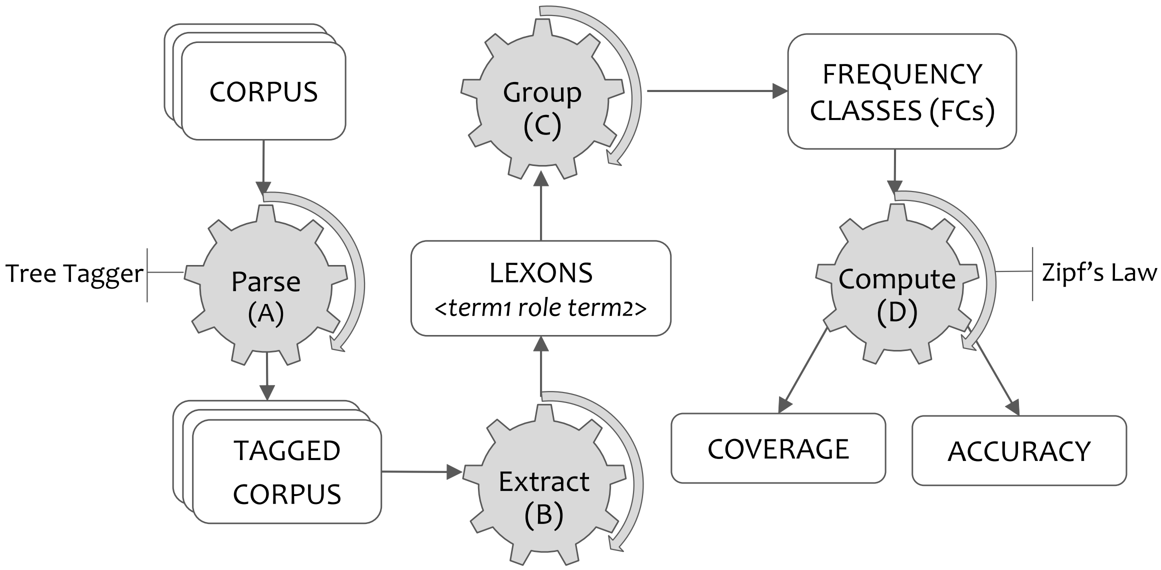


Figure 5.1: The process used for the quantitative evauation

B In the step B, from the *tagged corpus* triples composed by two nouns and a verb are extracted and normalized to the root form (i.e. singular for the nouns and infinitive for the verbs). These triples are successively formatted to generate a list of *lexons*.

C In the step C, the frequency of the lexons over the corpus is computed. Consequently, the lexons with the same frequency are grouped defining several *frequency classes* (FCs).

D In the step D, the frequency classes previously defined are used to compute both coverage and accuracy. The coverage function is measured by counting for each frequency class the number of lexons that are both in the corpus of documents and in the ontology, representing how much the terms defined in the ontology cover the represented domain. In the same way, the accuracy is estimated on the basis of the coverage percentage for a limited interval of frequency classes. In order to select the most relevant range of frequency classes for measuring the accuracy, we apply the Zipf's law principle (Zipf, 1949). This law states that the occurrence of a word in a corpus of documents is inversely proportional to its frequency class. This means that words with higher frequency are less meaningful for the corpus domain than words with less frequency. A similar idea has been published in (Luhn, 1958), where authors state that the most significant terms for a domain are in the middle frequency classes. For these reasons, we do not consider the words that belong to the highest frequency classes.

Within the scope of this thesis, the collection of documents for the corpus and consequently the evaluation of coverage and accuracy have been performed in two different parts depending on the considered domains. This choice is related to the affinity among considered domains. In particular, the first part regards the domains of accessibility, technology and emergency, while the second part aims to evaluate the domain of evacuation.

Coverage and accuracy for accessibility, technology and emergency

The documents collected for the corpus about accessibility, technology and emergency are several articles that have been suggested by the domains experts. This corpus has been also used during the development of the solution as domain of contrast for acquiring knowledge about evacuation (see Section 4.3.3). The corpus is formed by 67 articles from the proceedings of the conference ISCRAM (Intelligent Systems for crisis management) of 2007 (Various Authors, 2007), a manual developed by the North Central Texas regional government (North Central Texas Regional Government, 2013) and other articles about the role of communities within the emergency management ((Schafer et al., 2008), (Schafer et al., 2007), (Van De Walle and Turoff, 2007), (Carver and Turoff, 2007), (Turoff, 2002), (Turoff et al., 2004)). Additionally, the corpus has been enriched with the Web Content Accessibility Guidelines 1.0 with W3R Recommendation published the 5th of May, 1999 and 24 articles from the website called Web Accessibility in Mind (Center for Persons with Disabilities and UtahState University, 2013).

As already explained, we analyse the whole corpus in textual form and tag each word with its syntactic function (i.e. nouns, verbs, adjectives, etc.). We extract just nouns and verbs in their root form in order to generate a list of lexons. These leoxns are successively compared with the ones generates from SEMA4A. On the one hand, computing the coverage means investigating how much the SEMA4A lexons cover the corpus and more importantly how accurate they are. To do this, we count for each frequency class the number of SEMA4A lexons that are also contained in the corpus and compare this number to the cardinality of the overall frequency class, obtaining a 32,56%.

On the other hand, computing the accuracy means determining exactly which frequency class contains the terms most characteristic for a domain. This function depends mainly on subjective opinions and experience in the knowledge area. Analysing the frequency classes, we have categorized them looking at how much terms in each class are representative for the considered domains. The obtained result is the following categorization, where FC refers to the value of the frequency class:

- FC $<$ 9 contains many non-words (e.g. 'jj', 'rb') and too generally related to the domain (e.g. 'covenant', 'downtown', 'eastward').
- 9 $\leq$ FC $<$ 350 contains technical language related to the domain.
- 350 $\leq$ FC $<$ 600 contains general language used in a technical sense.
- FC $\leq$ 600 contains function words and highly used general language terms (e.g. 'exercise', 'example', 'information').

Based on the Zipf's law principle, the accuracy has been computed over the frequency classes in the central range (i.e. 9 $\leq$ FC $<$ 600), cutting off the lowest and the highest ones. Thus, the obtained value for the accuracy (i.e. the percentage of lexons belonging to the ontology that cover the corpus) is 42,24%. Figure 5.2 shows two graphs: the darker one represents the frequencies of the lexons over the corpus, while the lighter one represents the frequencies of the lexons over the ontology. In particular, on the horizontal axis there are the values of the frequency classes, while on the vertical axis there is the number of lexons contained in the classes. The accuracy is represented by how much the lighter part covers the darker part. For a more readable image, the graphs have been limited to the range 9 $\leq$ FC $<$ 230.

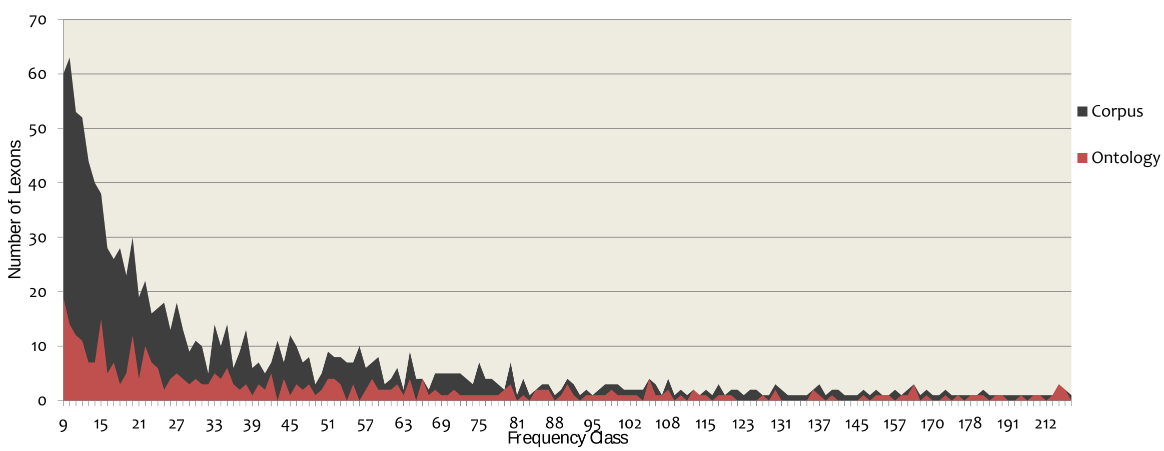


Figure 5.2: The accuracy for accessibility, technology and emergency (9 $\leq$ FC $<$ 230)

Coverage and accuracy for evacuation

In this second part, we are going to compute coverage and accuracy for the domain of evacuation. Following the same technique of the previous part, we collect lexons as relations included in the ontology from the domain of evacuation. In order to measure the coverage and the accuracy, we are going to use the same corpus of documents already employed during the knowledge identification phase for developing the proposed solution (see Section 4.3.2). This corpus is composed by several academic and research contributions like books, papers or journals about evacuation models and simulations and technical reports published by official channels like evacuation guidelines, plans or procedures.

In this case, we have collected 362 frequency classes. In the lower one the lexons occur just one time and in the higher one the lexons have a frequency of 5818. Computing the coverage of these lexons over SEMA4A, the obtained ratio is 58,9%. About the accuracy, we need to select a specific range of classes. Taking into account the Zipf's law principle, the selection of the most relevant classes has been done manually looking at the meanings of each term. Moreover, we use the domain relevance and domain consensus (i.e. DR, DC) already computed in the knowledge acquisition phase (see Section 4.3.3) for determining the ratio of relevant terms for each frequency class. Finally, we have identified the following categories:

- FC $<$ 28 contains general words not directly related to the domain (e.g. 'proximity');
- 28 $\leq$ FC $<$ 500 contains general words that acquire a specific meaning if used in the domain (e.g. 'access');
- FC $\geq$ 500 contains specific words for the domain (e.g. 'evacuation').

Respect to the theory of Luhn (Luhn, 1958), we have found the most specific terms for the domain in the higher classes. This fact is related to the kind of documents we have collected in the corpus, where many of them employ a technical language. Computing the accuracy in the range from the frequency classes , the obtained ratio is 64,2%. As in the previous part, in Figure 5.3 there are two overlapped graphs: the darker one represents the frequencies of the lexons over the corpus, while the lighter one represents the frequencies of the lexons over the ontology. On the horizontal axis there are the values of the frequency classes, while on the vertical axis there is the number of lexons contained in the classes. The obtained ratio for the accuracy is the coverage of the lighter part over the darker part.

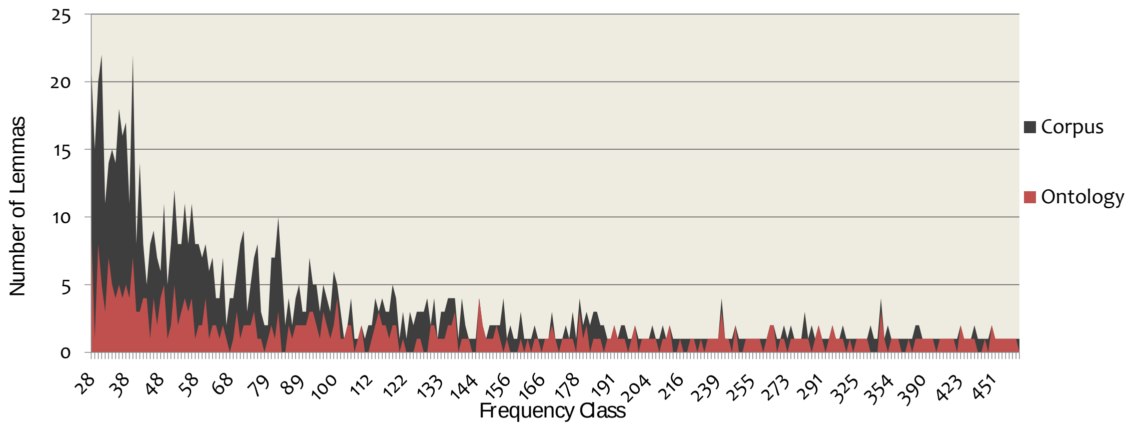


Figure 5.3: The accuracy for evacuation ($30 \leq FC < 230$)

Table 5.1: Comparison between coverage and accuracy obtained for the domains of accessibility, technology and emergency, and the domain of evacuation

Domains	Coverage	Accuracy
Accessibility, technology and emergency	32,56%	42,24%
Evacuation	58,9%	64,2%

For a more readable image, the graphs have been limited to the range $30 \leq FC < 230$.

From a lexical point of view, the measure for the accuracy is a very good result probably due, not only to the used corpus, but also to the novel methodology we have adopted for the term extraction (see Section 4.3.3). It is worth noting, we have employed a different methodology for acquiring knowledge between the domains of accessibility, technology and emergency and the domain of evacuation. This change is reflected in particular in the values of coverage and accuracy for the different domains (see Table 5.1). The ratio for the coverage is 32,56% for accessibility, technology and emergency, while it is 58,9% for evacuation. In the same way, the ratio for the accuracy is 42,4% for accessibility, technology and emergency, while it is 64,2% for evacuation.

5.2 Qualitative Evaluation

In order to evaluate qualitatively the ontology, we follow a procedure inspired by the HCOME methodology (Kotis and Vouros, 2005), already described in Section 2.2. According to HCOME, experts of the considered domains collaborate and cooperate in order to define a common knowledge base. Within the scope of this thesis, the domain experts have been involved to evaluate the list of lexons defined in the SEMA4A ontology. To do this, we prepare a questionnaire where each question is associated to a particular function to measure: coverage, accuracy or precision. While coverage and accuracy have been already introduced within the previous quantitative evaluation, here we are also interested in evaluating in the meanings of retrieved terms and their relevance respect to the domains. For this reason, also the precision is considered. The coverage, the accuracy and the precision are traduced into the following three questions:

- Have all the lexons to be discovered actually been discovered? (i.e. coverage)
- Are the lexons not too general but reflecting the important terms of the domain? (i.e. accuracy)
- Are the lexons making sense for the domain? (i.e. precision)

These questions have been specifically translated as the following for each lexon in the lists:

A Is the lexon in the domain? (i.e. coverage), where the possible answers are *yes* or *no*.

B Does the lexon make sense for the specific domain? (i.e. accuracy), where the possible answers are *yes* or *no*.

C What is the level of precision of the lexon? (i.e. precision), where the possible answers are *specific*, *not too specific* or *general*.

We assigned different discrete values to the possible answers: 0/1 for yes/no to the questions of type A; 0/1 for yes/no to the questions of type B; and 1/2/3 for specific/not too specific/general to the questions of type C. The answers to the questionnaire are successively analysed to compute the three functions. Moreover, the collected comments and suggestions from the experts are employed to filter and improve the ontology. As for the quantitative evaluation, also the qualitative evaluation has been performed in two parts. During the first part we are going to interview two experts in the areas of accessibility and emergency. In the second part, the involved experts are about evacuation procedures and plans.

Questionnaire about accessibility, technology and emergency

For the domains of accessibility, technology and emergency we have involved two evaluators. The first one is an expert of accessibility who worked several years for both international and Spanish R&D (i.e. Research and Development) projects. She is particularly expert on Infometrics (i.e. information measurement) applied to web accessibility. The second evaluator is a professional working for the Spanish Civil Protection and developing documents, policies and recommendations about the emergency domain. The experts were asked to evaluate the value and usefulness of the lexons extracted from the ontology in building a knowledge base for their specific domain of interest. The domain of technology has been evaluated in relation to the domains of accessibility and emergency.

The evaluation questionnaire have been presented in an Excel file with a list of lexons and for each lexon the three questions. For each evaluators, just the lexons related to the domain of expertise have been selected and presented. In this way, we have generated two different lists: one with emergency lexons evaluated by the emergency expert and another one with accessibility lexons evaluated by the accessibility expert. Moreover, we have reduced the selection of lexons to hundreds of terms by matching them with the ones also present in the corpus. This is due to the fact that a human evaluator can be prompted with hundreds of terms and not with thousands (used in the quantitative evaluation). For the same reason, we have sent the questionnaire by email in order to give them the freedom to respond respecting their occupations (i.e. about a month).

The expert on accessibility evaluated 155 lexons extracted from our ontology and related to the accessibility domain. The obtained results are a coverage of 91% (i.e. answers *yes* to the question A), an accuracy of 84% (i.e. answers *yes* to the question B) and a precision of 79% (i.e. answers *specific* to the question C). For the precision, the expert also rated a 9% of the lexons as *not too specific* and a 12% of the lexons as *general*. The expert on emergency evaluated 265 lexons about the emergency domain. The obtained results in this case are a coverage of 66% (i.e. answers *yes* to the question A), an accuracy of 45% (i.e. answers *yes* to the question B) and a precision of 65% (i.e. answers *specific* to the question C). The other answers for the precision are a 1% of *not too specific* lexons and a 34% of *general* lexons. These results are resumed in Table 5.2.

Table 5.2: Obtained answers for the qualitative questionnaire with the experts in accessibility and emergency

	Question A		Question B		Question C		
Expertise	Yes	No	Yes	No	Specific	Not too specific	General
Accessibility	91%	9%	84%	16%	79%	9%	12%
Emergency	66%	34%	45%	55%	65%	1%	34%

The results obtained from the questionnaire show an assessment about the quality of the ontology as representation for the domain of accessibility. The difference between the results obtained from the two experts is mainly due to the fact that the emergency portion of our ontology has been automatically built by extracting relevant information from a corpus of documents suggested by experts; while the accessibility part has been built by integrating ontologies that were already verified and cleaned. Figure 5.4 shows the average scores on coverage, precision and accuracy as evaluated by experts over the accessibility, technology and emergency components of SEMA4A.

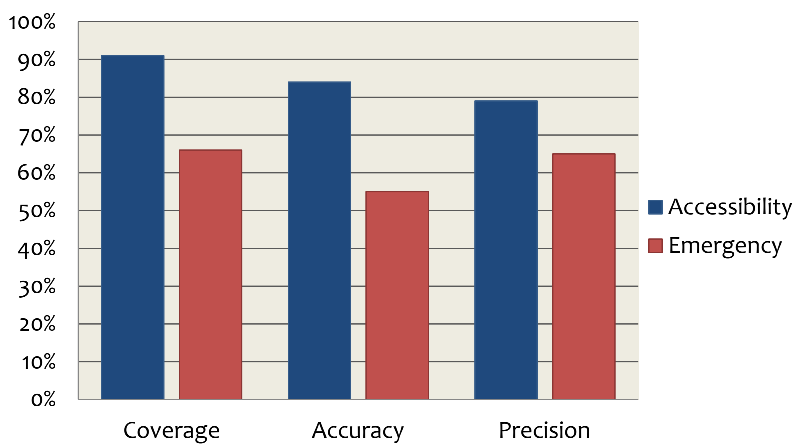


Figure 5.4: Average scores on coverage, precision and accuracy for the questionnaire about accessibility, technology and emergency

From the qualitative evaluation, we have collected suggestions and opinions useful for improving the ontology. In particular, we filter out from SEMA4A terms that experts have judged too general or not specific for the considered domains. For example, terms like "Link_location_attribute" (i.e. the attribute location for the link element of an html page) or "Link_AccessKey" (i.e. the attribute short-cut key for the link element of an html page) are judged too peculiar, while terms like "novice" are judged too general for the accessibility expert. From the emergency point of view, experts consider too general terms like "attention" or "removal", while terms like "finite_quantity" or "unfortunate_person" are too peculiar for the emergency domain.

After that, we run a second iteration of the previous quantitative evaluation onto the same corpus but with a reduced set of concepts due to the filtering phase. The new ratio for the coverage over the filtered frequency classes is 70.04%. The accuracy is computed in the range $9 \leq \text{FC} \leq 230$ with a ratio of 74.42%. In Figure 5.5, the accuracy after the filtering phase is represented, where the darker part represents the frequencies of the lexons over the corpus and the lighter part represents the frequencies of the lexons over the ontology. The horizontal axis represents the values of the frequency classes, while the vertical axis represents the number of lexons in the classes.

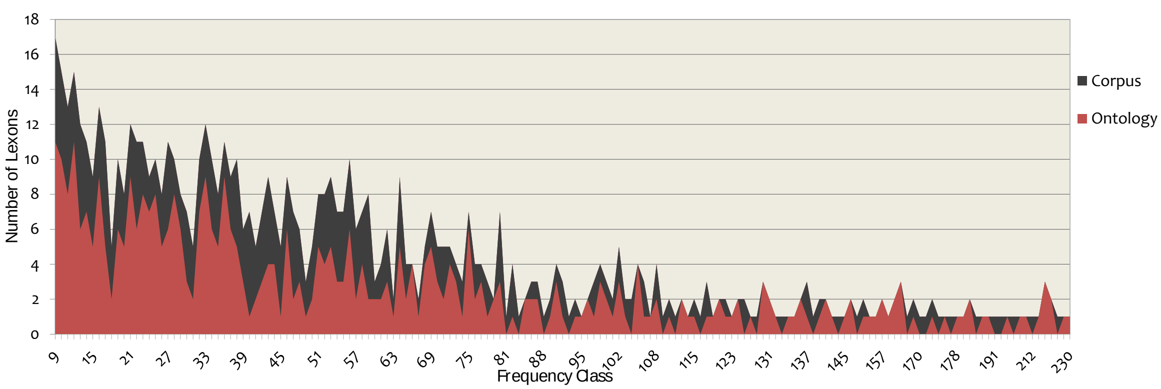


Figure 5.5: The accuracy for accessibility, technology and emergency after the filtering phase ($1 \leq \text{FC} \leq 230$)

Table 5.3 compares the values of coverage and accuracy obtained pre and post the filtering phase. The considered range of frequency classes for the accuracy is lower than in the previous experiment since this time more relevant words are all compressed within lower frequency classes, as stated by the Zipf's law. Both the coverage and the accuracy result improved after the filtering phase thanks to cutting off the less representative terms for the domains of accessibility, technology and emergency.

Table 5.3: Comparison between coverage and accuracy pre and post the filtering phase for accessibiliy, technology and emergency

	Coverage	Accuracy	Range of FCs
Pre	32,56%	42,24%	9≤ FC ≤600
Post	70,04%	74,42%	9≤ FC ≤230

Questionnaire about evacuation

As experts about evacuation procedures and plans, we have involved five international evaluators with the following profiles:

- three engineers in charge of evacuation plans for several Italian high schools;
- a security expert for chemical and fire risks within the Spanish Civil Protection and the city hall of Madrid;
- an engineer in charge of evacuation procedures for a Spanish railway company.

During the first part of the qualitative evaluation, the experts have encountered several difficulties in managing the lists of lexons in the Excel format. Consequently, an easy to use tool for visualizing and managing the lexons is needed for facilitating the involvement of the evaluators. For this reason, we have developed a visualization tool that allows an intuitive navigation and selection of terms and relations and improve the efficiency of the evaluation activity (see Figure 5.6).

The tool is a Web platform organized in five areas. In the central area, a portion of the ontology is visualized where the terms are represented by circles and the relations by arcs. The circles can be of different colours depending on the belonging frequency class. The entire ontology is show on the right as a graph that can be explored moving a box. While the circles represent individual terms, the diamonds are groups of terms. In this way, we aim to facilitate the navigation of the ontology. Moreover, on the right there is a short legend to interpret correctly the graph, while on the left there is a textual list of the terms that are currently shown in the central area. Clicking on a term, the associated relations are shown. Clicking on an arc of the graph in the central area, a box for modifying or deleting the couple of terms and the relation is shown. In Figure 5.6, the selected relation is the triple $<impairment, may\_have\_difficulty, door>$. Each one of this relation correspond to the list of lexons to evaluate.

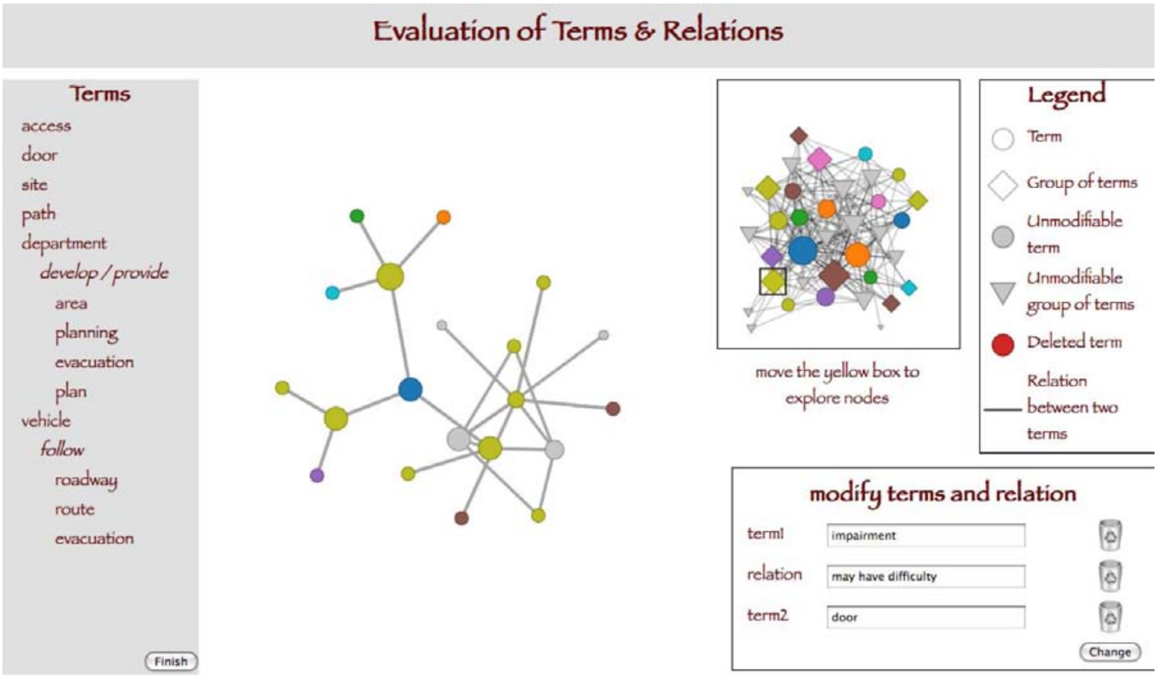


Figure 5.6: The developed visualization tool for supporting the qualitative evaluation

Evaluators have been interviewed face to face for about one hour using the visualization tool. In this way, the experts can navigate the lexons and eventually modify or delete them, while we collect their opinions and suggestions. In particular, we have asked them to evaluate the three criteria of coverage, accuracy and precision in form of the already pointed out questions (i.e. A,B and C) over the portion of SEMA4A about the domain of evacuation. Obtained results from each evaluator are summarized in Table 5.4, while average values for coverage, precision and accuracy are presented in Figure 5.7 as a bar graph.

Table 5.4: Coverage, accuracy and precision for each evaluator of the evacuation domain

Criteria	Evaluator 1	Evaluator 2	Evaluator 3	Evaluator 4	Evaluator 5
Coverage	98,36%	97,70%	90,48%	97,87%	97,87%
Accuracy	92,78%	92,28%	86,70%	94,42%	93,00%
Precision	95,89%	95,24%	87,03%	95,57%	89,00%

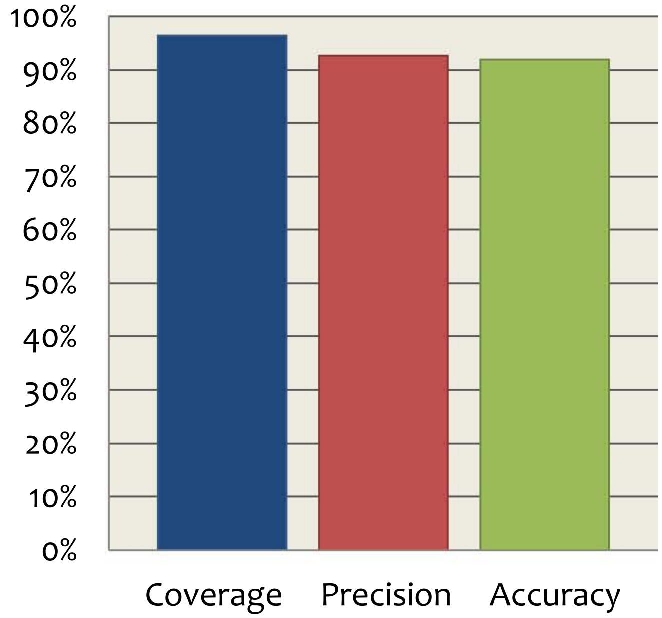


Figure 5.7: The average scores for evacuation

Computed values for coverage, precision and accuracy are all above the 85%. This means that the evaluators consider the ontology an high quality representation for the domain of evacuation. These results confirm also the effectiveness of the applied technique for extracting terms and relations and computing their relevance. Nevertheless, this is also a consequence of the corpus selected during the knowledge identification step: all documents used for acquiring knowledge about evacuation procedures were very specific and many of them written with a technical language.

As already done in the previous part about accessibility, technology and emergency, the comments collected from the interviews with the evaluators have been used for improving the ontology. The lexons have been filtered modifying or deleting the less representative terms and relations. After that, we perform a second iteration of the quantitative evaluation over the same corpus. In this case, the number of the lexons in the frequency classes has been reduced by the filtering phase. The coverage ratio reaches a 65,4%, while the accuracy ratio is about 76,9% computed in the same range of frequency classes of the first iteration (i.e. $28 \leq FC < 500$). In Figure 5.8, the accuracy is represented: the darker part represents the lexons over the corpus while the lighter part represents the lexons over the ontology. The horizontal axis represents the frequency classes, while the vertical axis concerns the number of lexons in each class. For a more readable figure, we limit the graph to the FC $\leq$ 300.

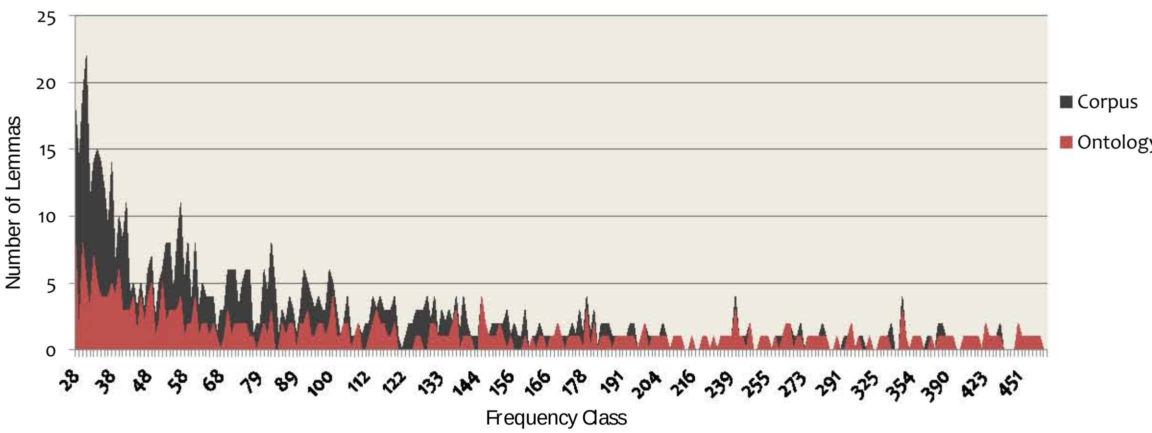


Figure 5.8: The accuracy for evacuation after the filtering phase (28 $\leq$ FC $\leq$ 300)

In Table 5.5, we compare the values of coverage and accuracy obtained pre and post the filtering phase. The considered range of frequency classes for the accuracy is the same in both cases. The two semantic functions have been improved by the filtering phase thanks to the results collected from the domain experts. In particular, the qualitative filtering has dropped down the less specific or too general terms and relations. It has also modified the ambiguous ones, improving the representative value of the ontology.

Table 5.5: Comparison between coverage and accuracy pre and post the filtering phase for evacuation

	Coverage	Accuracy	Range of FCs
Pre	58,9%	64,2%	28$\leq$ FC $\leq$500
Post	65,4%	76,9%	28$\leq$ FC $\leq$500

5.3 Consistency

The aim of this section is to verify if the SEMA4A ontology is consistent. An ontology is consistent if included concepts and relations are syntactically not redundant and meaningless (Tarski, 1941). Consequently, checking the consistency depends on the syntax and the language used for implementing it.

In this thesis, we have implemented SEMA4A using OWL (i.e. the Ontological Web Language already introduced in Section 4.4). This language is based on the description logic where rules and properties have been standardized by the W3C (i.e. World Wide Web Consortium) (Motik et al., 2009). A consistent syntax for SEMA4A means verifying if the standard rules of OWL has been met by the implementation. To do this, several reasoning tools based on the description logic have been developed (e.g. FACT++ (Tsarkov and Horrocks, 2006) and HermiT (Glimm et al., 2010)). All of them take a knowledge representation as input and give as output a possible value among *Consistent*, *Inconsistent* and *Unknown*.

Here we decide to use the reasoner tool developed by Sirin and Parsia in (Parsia and Sirin, 2004) and called Pellet. In particular, we used the command line version. This tool provides several services for reasoning ontologies, including (Sirin et al., 2007):

- the *consistency checking* for guaranteeing a standard knowledge representation;
- the *concept satisfiability* for ensuring that each concept in the ontology can be instantiated;
- the *classification* for establishing the entire class hierarchy and its completeness;
- the *realization* for finding the right belonging class for each individual in the ontology.

Among these services, we run both the consistency checking and the concept satisfiability. The command for the consistency checking is

```
$>pellet consistency path_ontology/sema4a.owl
```

and running it we obtain `Consistent: Yes` as result. The command for the concept satisfiability is `$>pellet unsat path_ontology/sema4a.owl`, and running it we obtain the following result:

```
Finding unsatisfiable 2533 elements
Finding unsatisfiable:  100\% complete in 00:00
Finding unsatisfiable finished in 00:00

Found no unsatisfiable concepts.
```

After running these two services and considering the obtained positive results, we can conclude that the SEMA4A ontology is consistent and each concept in the ontology can be instantiated.

5.4 Interoperability

The last property for the SEMA4A ontology is the *interoperability* with other solutions in the emergency area. In particular, it is related to the ability to share and coordinate information among different kinds of systems. To do this, it is crucial to employ a standard language that facilitate the communication abilities. Within this scope, the World Wide Web Consortium (W3C) in collaboration with Noy, McGuinness and Hayes has defined several formal recommendations for guaranteeing the interoperability of XML-based ontology languages (Noy et al., 2013). The result is a set of five principles that can be employed to develop an interoperable ontology. In the following sections, we are going to introduce briefly each principle explaining also how it has been achieved into SEMA4A.

5.4.1 Principle 1

The first principle states that creating new ontologies in OWL facilitates the interoperability. In fact, OWL is an XML-based language standardized by the W3C (World Wide Web Consortium (W3C), 2013a). For this reason, it can be easily accessed by other standards or platforms. Moreover, several query languages for querying OWL ontologies have been defined. Nowadays, this language is widely used in the ontology engineering area, but there are still many existing ontologies written in other formats.

As already introduced in Section 4.4, the SEMA4A ontology has been implemented using OWL as ontology language. Moreover, we have evaluated its consistency with the Pellet reasoning tool (see Section 5.3). In this way, we guarantee a consistent definition for the concepts and the relations included into SEMA4A.

5.4.2 Principle 2

The second principle focuses on the efficiency of translating existing ontologies into OWL to facilitate the interoperability. If we want to guarantee an interoperable result from merging existing ontologies that are written in other languages, it is required to translate them into OWL. The difficulty of this activity depends on the kind of language to translate. In particular, it is easiest to transform ontologies written using a kind of first-order logic.

Within the development of SEMA4A, two existent ontologies has been merged: WAfA and AccessOnto, both of them already implemented in OWL. For this reason, merging them in an interoperable ontology is compliant with this principle. Nevertheless, there could be the possibility of defining ambiguous elements. This problem is discussed in the fifth principle.

5.4.3 Principle 3

The third principle is about reducing the ambiguity by specifying more meanings for each element in the ontology. In particular, in the area of Semantic Web, specifying the meanings of an entity is important to clarify its role within its context. This idea can be applied to the ontology development. Specifying the meanings that a term or a relation can assume facilitates its usage and consequently its interoperability with other solutions. This is related not only to the creation of a detailed vocabulary, but also to the definition of a complete structure. For example, saying that *Dog* is a subclass of *Animal* adds an additional information to the meaning of the term.

Once the concepts and the relations to be included to SEMA4A have been identified, we have detailed them adding associated meanings. To do this, we use the WordNet (Miller et al., 1990) language ontology. This ontology is an English dictionary where for each term several meanings, synonyms and other semantic relations are defined. We import these meanings for each concept in SEMA4A in order to specifying them. For example, Figure 5.9 shows the meanings included for the concept *Emergency*.

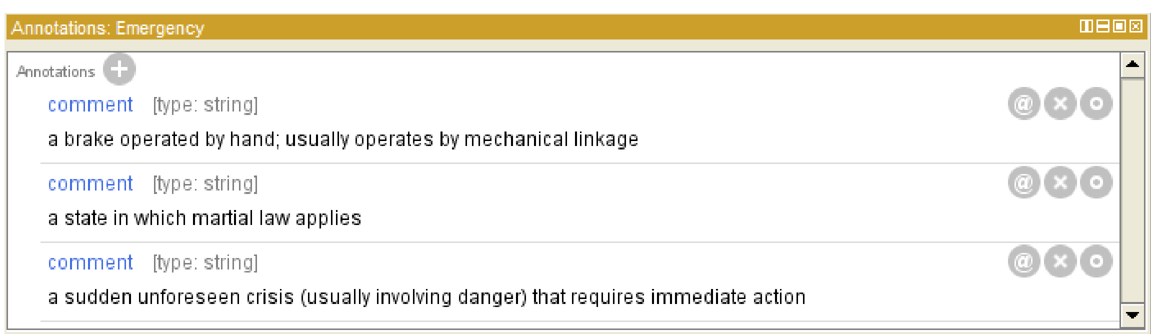


Figure 5.9: The meanings included for the concept *Emergency*

5.4.4 Principle 4

The scope of the fourth principle is related to the possibility of reusing terms already defined into existing ontologies. Considering the importance of specifying the meanings of the entities within the Semantic Web (as explained in the third principle), it is useful to reuse the content already detailed in other representations. To do this, it is crucial to ensure that the reused information is related to the same context. Moreover, this is facilitated by a standardization of considered information through XML-based languages as OWL.

As shown for the second principle, during the development of SEMA4A we have decided to reuse existing information about the domain of accessibility. After the analysis of ontologies previously developed in the area of accessibility, we found out that WAfA and AccessOnto already include the data needed for our solution. For this reason, we decided to reuse them

5.4.5 Principle 5

The fifth principle introduces the crucial role of the OWL constructs for mapping the terms belonging to different ontologies. In order to avoid any possible ambiguity, the merging or reusing of existing content has to be performed among standard languages. In this way, it is possible to link directly the standard definition or structure of the considered concepts or relations. Moreover, it is important to guarantee a semantic connection with the content already in the ontology. OWL gives the possibility to facilitate this task through a wide variety of constructs (e.g. `owl:equivalentClass` or `owl:equivalentProperty`).

In order to merge adequately the existing ontologies about accessibility with SEMA4A, it is crucial to identify if there are terms in common or with similar meanings between WAfA and AccessOnto. In this way, we can avoid possible ambiguities or misunderstandings.

The merging activity has been performed manually with the support of the WordNet (Miller et al., 1990) language ontology for identifying any similarities between the meanings of the terms and the relations. The completeness and the consistency of the obtained result have been already evaluated syntactically (i.e. with the quantitative evaluation in Section 5.1) and semantically (i.e. with the qualitative evaluation in section 5.2).

5.5 Results of the Evaluation

At the beginning of this chapter, we have identified several properties that the proposed architecture has to achieve. In particular, within the architecture the most critical module is the knowledge representation that has been developed as an ontology called SEMA4A. For this reason, the SEMA4A ontology is asked to satisfy identified properties, as shown in the previous sections. In Table 5.6, the four properties and the results of their evaluations are summarized.

Table 5.6: Association between the objectives and the design goals

Property	Evaluation
1. *Consistency* - avoiding redundancies and misunderstandings in the definition of terms and relations.	We have run two services of the reasoner tool Pellet developed by Sirin and Parsia in (Parsia and Sirin, 2004): the consistency checking and the concept satisfiability. Both of them give a positive result meaning that SEMA4A is consistent and each concept in the ontology can be instantiated.
2. *Completeness* - covering in depth a broad domain of information. 3. *Understandability* - making the representation comprehensible for human beings.	We have measured three functions called coverage, accuracy and precision in three steps. The first step is a quantitative evaluation. The second step is a qualitative evaluation with the involvement of several domain experts in accessibility, emergency and evacuation. During the third step, the comments collected from the experts have been used for filtering and improving the ontology. Moreover, another quantitative evaluation has been run. Finally, the values for the three functions reach an average ratio of 70%. In particular, the coverage and the accuracy are referred to how much SEMA4A covers the considered domains (i.e. the completeness over accessibility, technology, emergency and evacuation). The precision represents how much SEMA4A makes sense for human beings (i.e. understandability).
4. *Interoperability* - sharing and coordinating represented information.	We have verified that SEMA4A achieves each one of the five principles identified by Noy, McGuinness and Hayes in (Noy et al., 2013) as a W3C initiative. These principles are formal recommendations for guaranteeing the interoperability of XML-based ontology languages.

Chapter 6

Use Cases

As explained previously, SEMA4A is a consistent and complete ontology that can interoperate with other tools or platforms for managing emergencies and evacuation procedures. In this chapter, we are going to show the applicability of SEMA4A through several use cases developed within several research projects of the DEI Group of the University Carlos III of Madrid [3] in collaboration with the Spanish Civil Protection. All of them are notification systems, but each one offers different services. The first one, called CAPONES, sends emergency alerts adapting the content and the visualization to the needs of involved users. The second system is NERES which aims to generate and notify personalized evacuation routes. The last case we are going to present here is the EmergenSYS platform that provides three different mobile tools for sending alerts in two directions: from citizens to emergency operators and from emergency operators to citizens.

6.1 CAPONES

The first use case for the applicability of the SEMA4A ontology is CAPONES (published in (Malizia et al., 2009a) and (Malizia et al., 2009b)). It is a prototype for automatically creating and sending personalized emergency notifications using different media and devices. The main idea is to collect emergency information and, through the ontology, send it to the media and devices which better fit the abilities of the users.

In Figure 6.1, the architecture of the prototype is shown. It gets two inputs: an emergency alert in CAP format and a set of users' profiles that includes their

[3] Website of the DEI Group, http://www.dei.inf.uc3m.es

abilities and available devices. These inputs are successively parsed to extract the most relevant data and standardize them into a XML-based internal representation (part (A) in Figure 6.1). Successively, using this internal representation CAPONES performs queries on the SEMA4A ontology in order to adapt the alert notifications according to users' abilities and the kind of emergency (part (B) in Figure 6.1). It is worth to note that not only the profile of the users but also the characteristics of the emergency can affect the communication channels and the content of the notifications, as already specified in the definition of the proposed solution. The result obtained from the performed queries is a set of media and devices accessible for involved users and in the particular context of the emergency. This information is finally processed in order to send the adapted notifications (part (C) in Figure 6.1).

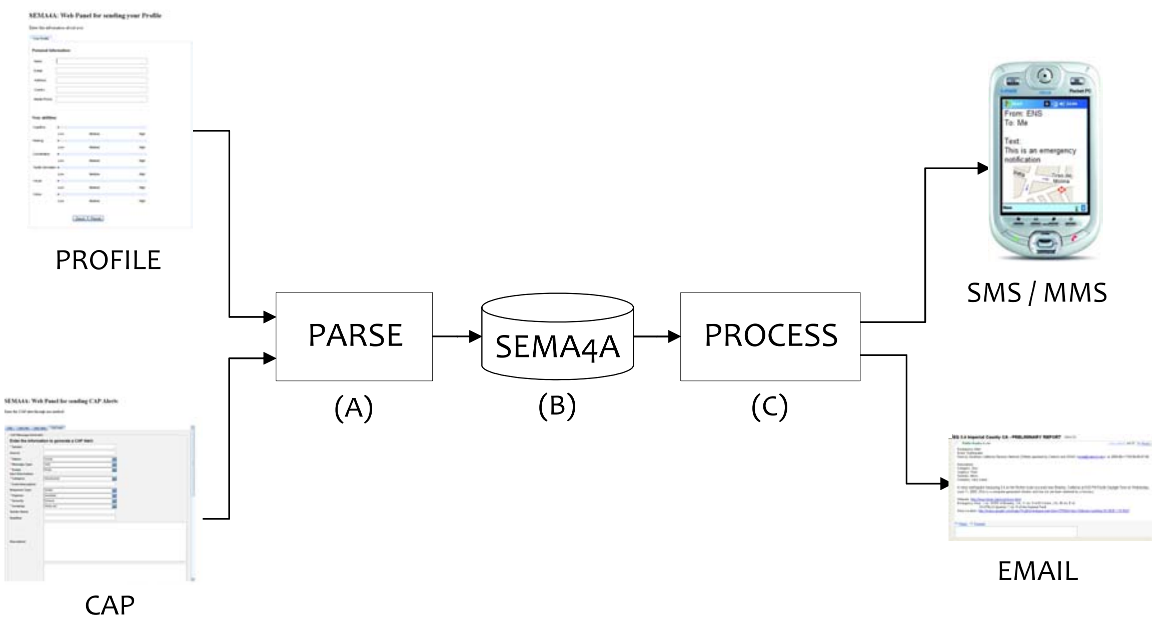


Figure 6.1: The architecture proposed for CAPONES: (A) Parse the CAP alert and the users' profiles in input; (B) Query SEMA4A with the parsed data; (C) Process the output of the query to sent the adapted notification

In the following subsections, we are going to describe each module of the architecture: the parse, the ontology and the process.

6.1.1 The Parse module

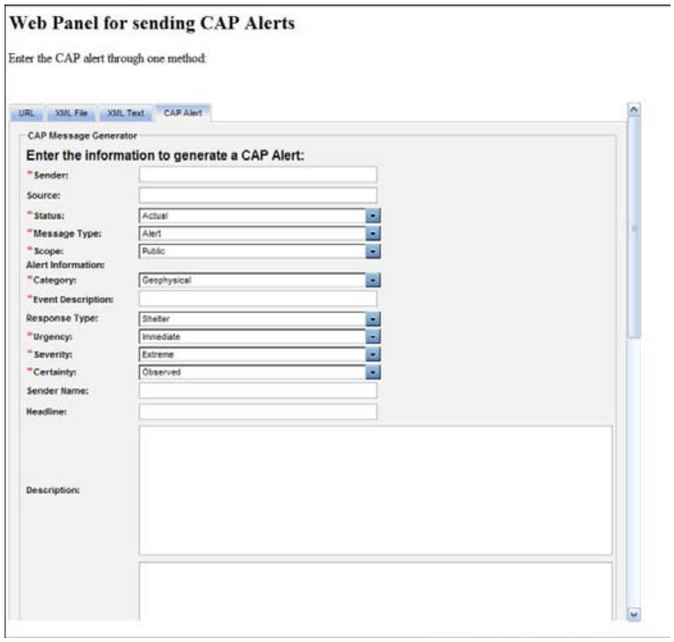
The Parse module (part (A) in Figure 6.1) manages the CAP alerts and the users' profiles taken as inputs. The emergency information to be processed is extracted from the CAP alerts, where CAP stands for the Common Alerting Protocol and it has been already introduced in Section 2.1.3. Considering that CAP is extensively used in the area of emergency management for sharing alerts, we decided to use this standard to guarantee the interoperability with existing systems in the same area. The Parse module allows to enter information about emergency situations through different ways: via a Web form (see part (a) in Figure 6.2), by importing a CAP file or directly providing an URL pointing at a CAP file. In this way, it is possible to receive CAP messages from other repositories or notification mechanisms (e.g. the EDIS - Emergency Digital Information Service, provided by the California Office of Emergency Services).

The information about the users is the second input of the prototype. The idea is to allow users to enter their profiles by their-selves or by the support of an assistant or a relative in case they cannot do it. For this purpose, a Web interface (see part (b) in Figure 6.2) has been developed for entering the following data:

- personal and contact information, including name, location data (i.e. address, country), mobile phone number and email.
- levels of the user's abilities among low, medium or high in six different categories, including *Cognitive*, *Hearing*, *Coordination*, *Tactile Sensation*, *Visual* and *Colour*. These categories correspond to the concepts, the properties and the restrictions codified in the ontology. It is worth to note that we use a positive representation of the abilities in order to consider not only permanent disabilities (e.g. being deaf) but also situational ones (e.g. not being able to hear due to the noise).
- possible devices depending on the user's level specified in the abilities section. From these levels, a list of compatible devices is extracted from the relations defined in the ontology. The users have to select all the possible combination of media (e.g. email, sms, mms) that they can use to receive the emergency notifications.

6.1.2 The Ontology module

Once all the information about the CAP alert and the users' profiles is retrieved, a series of queries are executed on the ontology in order to get the characteristics to issue a personalized notification for each affected user. There are different implementations for querying ontologies. In this module, we use SPARQL (Simple Protocol and RDF Query Language), a W3C (World Wide Web Consortium)



(a) The CAP form

(b) The user's profile form

Figure 6.2: The forms for entering the two inputs: the CAP alert (a) and the user's profile (b)

recommendation that allows querying information to a RDF (Resource Description Framework) document. Based on the ontology structure and the information extracted from the CAP alert and the user's profile, the system performs the following queries on the SEMA4A ontology:

1. Retrieve the kind of emergency as defined in the ontology that better fits the description of the alert included in the CAP alert. The ontology includes the definition of emergency concepts and their properties, such as severity, urgency and certainty also included in the CAP. Through SPARQL, it is possible to select the concepts and properties that match with the description of the emergency included into the CAP message. Defining ad-hoc regular expressions, these concepts are evaluated in order to find the one that best fits to the considered context.

2. Retrieve the media that may be used for notifying the considered emergency. The SEMA4A ontology defines a series of media and relates them with kinds of emergencies using the property called *mayUse*. We query this property over SEMA4A from the emergency concept obtained in the previous step (1) in order to select the desired media.

3. Retrieve what can be communicated through the media obtained in the previous step (2). SEMA4A includes relations between the media and the different tools that can be used to communicate (e.g. email, sms). Through SPARQL, we query the property *can-communicate* to obtain the communication channels from the known media.

4. For each user's profile, retrieve the media that the user is able to manage, depending on included information. SEMA4A defines relations between impairments and media using the property *mayUse*, already mentioned in the second step, and relations between impairments and communication channels using the property *can-communicate*, already mentioned in the third step. Querying with SPARQL these properties, we finally obtain the channel that best fits with the kind of emergency and the users' profiles.

Image a CAP emergency alert about an earthquake in a specific location. First, we retrieve the ontology class that represents this particular emergency through the query (1). The result is the class *Earthquake*. Second, we retrieve the media that may be used by this particular emergency. Applying the query (2) to the ontology class *Earthquake* through the relation *mayUse*, we obtain the following devices: *tv*, *radio*, *mobile_phone*, *phone*, *internet* and *eye_tracking*. Third, we perform the query (3) to retrieve the communication channels that can be used to send notifications during an earthquake. Through the property *can-communicate*, the result of the query is: *Video*, *Sound*, *multiple_languages*, *Figure*, *Text*, *mms*, *email*, *sms* and *vibration*.

Fourth, The users affected by the emergency situation have filled out their profile using the Web form. Among specified information, in particular they have listed the devices and communication channels to use according to their abilities. In case of a person with deafness disability, the execution of the query (4) gives the following result: *mms*, *vibration*, *sms*, *Figure*, *Video*, *Text*, *text_enhancer* and *email*.

Finally we compute the intersection between the set of communication channels that the emergency may use and the media used by the profile obtained from the third and fourth query. The result is made of: *Figure*, *Text*, *mms*, *email*, *sms* and *vibration*. This means that during an earthquake, a deaf person can be notified through these communication channels. In the next module, we are going to explain how this information is used.

6.1.3 The Process module

Using the result set obtained from the queries executed on SEMA4A ontology for a specific emergency and user profile in the Ontology module, we have the devices and the communication channels that can be used to issue a notification. In addition to this, we also personalize the content of the message that suits the results and provides a notification adapted for each user. To do this, the appropriate content from the CAP alert is selected depending on the users' abilities, the specific emergency and the considered media. Moreover, we adapt the multimedia data and the geographic information depending on the used devices. We can, for example, send individual sms with a formatted text including only relevant information due to the limited size, or mms including multimedia resources from the CAP alert. Thanks to the modular architecture and the standard formats, the CAPONES prototype and in particular this module can be extended to support additional functionalities and communication channels.

6.1.4 Usage of CAPONES

In this section we present an example to clarify how CAPONES works in a real scenario. Among subscribed users in the system, here we are going to consider two profiles: a deaf person and a blind person. Inserting their profiles, the first user specifies the following media to receive the alert: email, text, figure, vibration, mms, and sms. While for the second user the selected channels are vibration, email, sound, speech, brailline.

Additionally, we use the following two emergency alerts in the form of CAP messages:

1. an earthquake occurred in California with a detailed description of the area where the emergency took place, including a circle definition with coordinates for latitude and longitude;

2. an update by the Department of Homeland Security that elevates the threat level from green/low to orange/high. Moreover, the alert contains an image as auxiliary resource, a textual description and a URL (Uniform Resource Locator) of its location.

Taking into account the users' profiles and the CAP alerts, the system analyses the scenario through each module of the defined architecture (see Figure 6.1). The obtained results are described in the following subsections for each modue.

The Parse module

This module takes as input both the users' profiles and the CAP alerts. The considered profiles are related to the impairments deafness and blindness. In particular, the affected users have specified which kind of media they can access: Figure and mms for deafness, and Sound for blindness, while Text, email, sms and vibration are for both of them. The two alerts carry information about the earthquake and its security update. In Figure 6.3, the execution of the Parse module is summarized.

PARSE

1st User	Profile: Deaf person	
	Media: email, text, figure, vibration, MMS, SMS	
2nd User	Profile: Blind person	
	Media: email, sound, speech, brailleline, vibration	
1st CAP Alert	Kind: Earthquake	Urgency: green/low
	Area: California (latitude, longitude)	
	Resources: map	
2nd CAP Alert	Kind: Earthquake	Urgency: orange/high
	Area: California (latitude, longitude)	
	Resources: figures, URL	

Figure 6.3: Execution of the Parse module

The Ontology module

Querying the SEMA4A ontology, CAPONES extracts details about the communication channels that can be used during the earthquake. To do this, a specific SPARQL query is defined and executed from the characteristics contained into the two CAP alerts in input. The result is that during an earthquake it is possible to communication through channels like tv, radio, mobile phone and internet. Moreover, the content of the notifications includes the following media: Figure, Text, Video, Sound, multiple languages, mms, sms, email, vibration. In Figure 6.4, the query executed over SEMA4A and the obtained result are shown.

ONTOLOGY

Query (specific media for the CAP alerts)

```
SELECT DISTINCT ?mu WHERE {
        ?emg rdfs:subClassOf ?object ;
                rdfs:subClassOf :Emergency .
        ?object rdf:type owl:Restriction ;
                owl:onProperty :mayUse ;
                owl:someValuesFrom ?emgmu .
        ?emgmu rdfs:subClassOf ?emgmusc .
        ?emgmusc owl:onProperty :can-communicate ;
                owl:someValuesFrom ?mu .}
```

Results

Channels: TV, radio, mobile phone, internet

Media: figure, text, video, sound, multiple languages, mms, sms, email, vibration

Figure 6.4: Execution of the Parse module

The Process module

This module takes the results of the queries over the ontology and processes them to personalize the notifications to send. Making an intersection between the sets of communication channels obtained for the users' profiles and the emergency alerts, we can observe that email, mms and sms are valid to send notifications to the deaf person, while e-mail and sms can be used for the blind person (since a text can be read by a text-to-speech tool).

From the earthquake alerts, the email notifications can contain both the Google Maps url for representing the geographical data and any other multimedia resources like figures or videos. The included data depend on the abilities of the users. In case of the deafness profile, it is possible to consider both maps and figures, while for the blindness profile the email contains a textual description of the area that can be read by a text-to-speech tool or a Braille technology.

Concerning the mms notification, it can contain both text and images extracted from the emergency alert and it is suitable for the deaf person. For the blind person, the notification can be sent using a sms that includes just a textual description of the situation. As in case of the email, also for the sms the user can access to the content through a text-to-speech tool or a Braille technology.

In Figure 6.5, the alerts and the included resources for the two profiles (i.e. deaf person and blind person) are summarized.

PROCESS	
Alerts	
1st User	Media: email, MMS, SMS
	Resources: text, map, figures
2nd User	Media: email, SMS (read by a text-to-speech tool)
	Resources: text

Figure 6.5: Execution of the Parse module

6.2 NERES

The second use case we are going to present in this thesis as example of the applicability of SEMA4A is NERES (Notification of Evacuation Routes in Emergency Situations). This is a notification system for personalized evacuation routes in indoor environments using portable terminals (e.g., mobile phones, PDAs, emails). The personalization depends on several variables: user's abilities and impairments, levels of expertise, needs and preferences, current location, available media and technology, the surrounding environment and context of the emergency (e.g. severity and evolution). It is important to clarify that people that may need special assistance during an emergency situation are not only those that suffer from permanent disabilities but also other groups with contextual disabilities. Within these groups, we consider in particular people unfamiliar with the building structure (e.g. visitors) or with limitations due to the event (e.g. fire smoke).

The entire system is based on the SEMA4A ontology to infer information about the personalization of alerts and evacuation routes, as for example which kind of devices or communication infrastructures is most suitable depending on users' abilities. The development of NERES is a complex mechanism that has to involve several crucial aspects for improving the evacuation procedures. These key aspects are:

1. The mechanism makes use of smartphones. Considering the increasing usage of smartphones, it is possible to make easier the evacuation process by informing affected people with updated information on where to go and how to reach the appropriate point directly with a message on their devices.

2. The mechanism includes a desktop application for the definition of evacuation plans and for monitoring the affected people from the Command Post through the use of interactive maps.

3. The mechanism provides a registration tool to save users' profiles, which will be used to personalize the notification alerts and evacuation routes.

4. The mechanism allows a bidirectional communication between the subscribed smartphones and the Command Post. In particular, the smartphones interact with the system sending their current location and receiving multimodal messages personalized according to the emergency situation, the personal context and their profile.

5. The mechanism selects the route that best meets the specified characteristics related to the user and the emergency situation among those defined in the official evacuation plan. In this way, delivered instructions do not interfere with procedures laid down by the Security Department, but they represent a support for performed activities within the official plan.

Taking into account these aspects, the proposed mechanism is composed of three components (see Figure 6.6):

- CAPONES (Common Alerting Protocol-based Open Notification System) personalizes the emergency notifications. It has been already introduced in the previous section (see Section 6.1).

- NERES (Notification of Evacuation Routes in Emergency Situations) personalizes the information about evacuation routes.

- iNeres is the mobile client side for receiving the notifications sent by NERES.

While CAPONES has been already described in the previous section (see Section 6.1), the following subsections introduce the NERES and iNERES components.

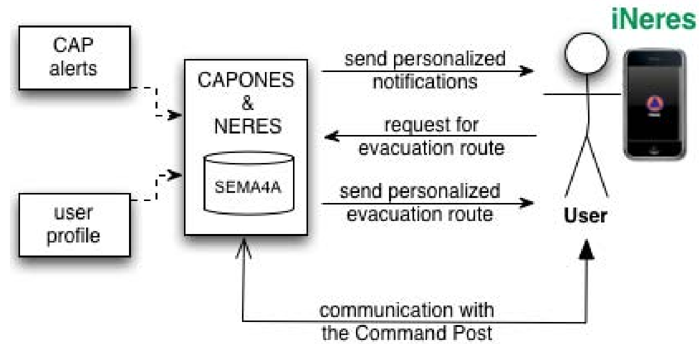


Figure 6.6: The proposed architecture for managing personalized alerts about emergency situations and evacuation routes

6.2.1 NERES and SEMA4A

The component NERES is a server application for generating personalized evacuation routes based on user profiles and contextual information about an emergency situation. In order to obtain instructions for responding adequately to the emergency, first a client application sends a request to NERES. Second, NERES generates a personalized evacuation route according to the user's current location, user's profile and the environmental data about the emergency. This is achieved by two different mechanisms: an evacuation plan data model and a back-end server application. The server application employs the data model to personalize the evacuation routes for each affected person who is registered in the system.

The evacuation plan data model gathers the entities required to represent the evacuation process of an emergency plan. It is represented by several concepts and relations defined in the SEMA4A ontology. All of them are subclasses of the *Evacuation* class that includes knowledge about evacuation procedures and plans. As already described in Section 4.3.5, the *Evacuation* class has a hierarchical structure with four subclasses: *Location*, *Personnel*, *Procedure* and *Transportation*.

The concepts for modelling the evacuation plan data are organized in the *Location* and *Procedure* classes and they are adequately related to the other classes of the ontology. Some of them are shown in Figure 6.7 as well as the most representative relations that will be explained in the following paragraphs.

- The relation *consider* (dark purple in Figure 6.7) is defined between *Impairment* and the classes *Evacuation*, *plan* and *place* to emphasize that each entity described within the evacuation plan has to take into account the users' abilities (or impairments).

- The relation *has_subclass* (light purple in Figure 6.7) is in charge of defining the hierarchical structure of this portion of concepts. In particular, from *Location*, subclass of *Evacuation*, there are *place*, *path* and *map*. From the other subclass of *Evacuation*, *Procedure*, there are *plan* and *point*. All of them are physical data about the environment.
- The relation *include* (yellow in Figure 6.7) specifies that *map* contains data about *route* and *Evacuation*.
- The relation *locate* (dark green in Figure 6.7) is established between *Evacuation* and *point* for defining the instructions to follow for escaping.
- The relation *may_have_difficulty* (light green in Figure 6.7) makes possible the adaptation of the evacuation plan to the users' abilities represented by the class *Impairment*. In particular, it is established between *Impairment* and the classes *path* and *plan*.
- The relation *use* (light brown in Figure 6.7) is established between *Evacuation* and the two classes *map* and *path* as instruments for defining routes to follow for escaping.

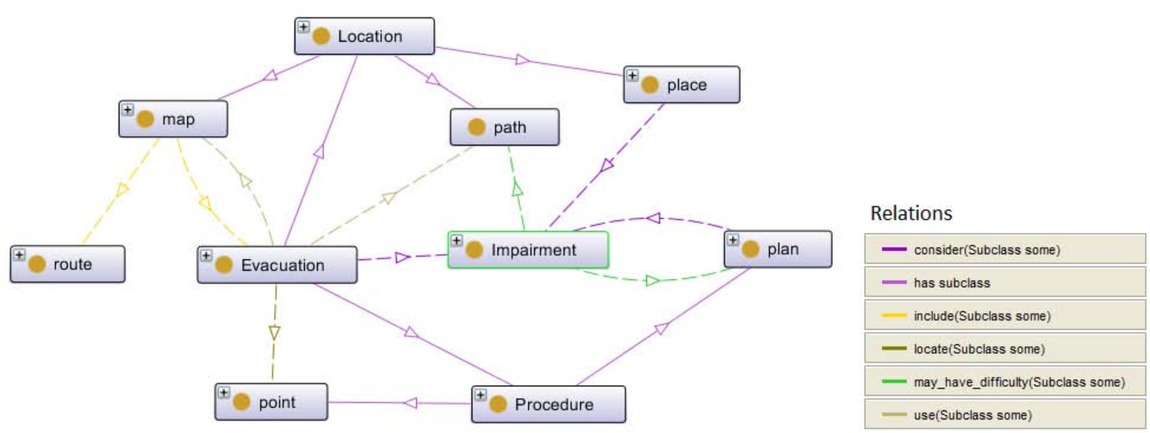


Figure 6.7: A part of the evacuation plan data model codified in the SEMA4A ontology

Through the evacuation data model, it is possible to infer the characteristics that the evacuation route has to follow. Knowing this information, NERES has to select the best route among the ones defined in the official evacuation plan. Apart from the portion shown in Figure 6.7, there are concepts as *corridor*, *door* and *road* representing the components of a route. Each one of them is also related to the ontology classes about users' characteristics, devices and context of use. In this way, it is possible to adapt the notifications. Within the scope of NERES, the personalization concerns both the instructions for escaping and the visualization mode of the routes. In particular, for different users' profiles and emergency situations, the selected visualization mode could change. For example, a text description is adequate for users with a visual impairment and a text-to-speech tool in their devices, while a map image is suitable for a person who knows the building and just wants to be sure about the position of exits or meeting points.

Based on the SEMA4A ontology, NERES is executed in two different phases of the emergency management process: preparedness and response.

During the preparedness phase, the planners must define an evacuation plan for each floor of the building and NERES is used to support this activity. In particular, they must define an evacuation route for each possible location of the users in the building (e.g. offices or rooms in a house) considering a set of predefined safety places as destination. In Figure 6.8, the tool used for the definition of the evacuation routes for a floor of the building is shown.

For each route, NERES verifies its accessibility by determining which user profile can access to its components. To do this, several queries over SEMA4A are executed as part for the personalization mechanism. For example, from SEMA4A it is possible to infer that people with mobility impairment cannot go down the stairs or through very narrow corridors and doors. Consequently, NERES can identify an incompatibility between routes that use stairs and these specific profiles, storing these data for the response phase.

During the response phase, once users have received an alert from CAPONES, they can send a request to NERES to get the best evacuation route specifying their location. First of all, NERES has to take into account any available contextual information about the current situation to establish if any area of the building has been affected by the emergency. In this way, such area is considered as dangerous making unavailable the evacuation routes in it. Secondly, NERES has to determine the optimal route from available information about the users' profiles and their location. To do this, the system follows these steps.

1. Using the location of the users, the system retrieves the nearest safety point and selects the possible evacuation routes among available ones.

2. Considering the contextual information about the emergency, the system filters out the evacuation routes in any dangerous area from the selected ones.

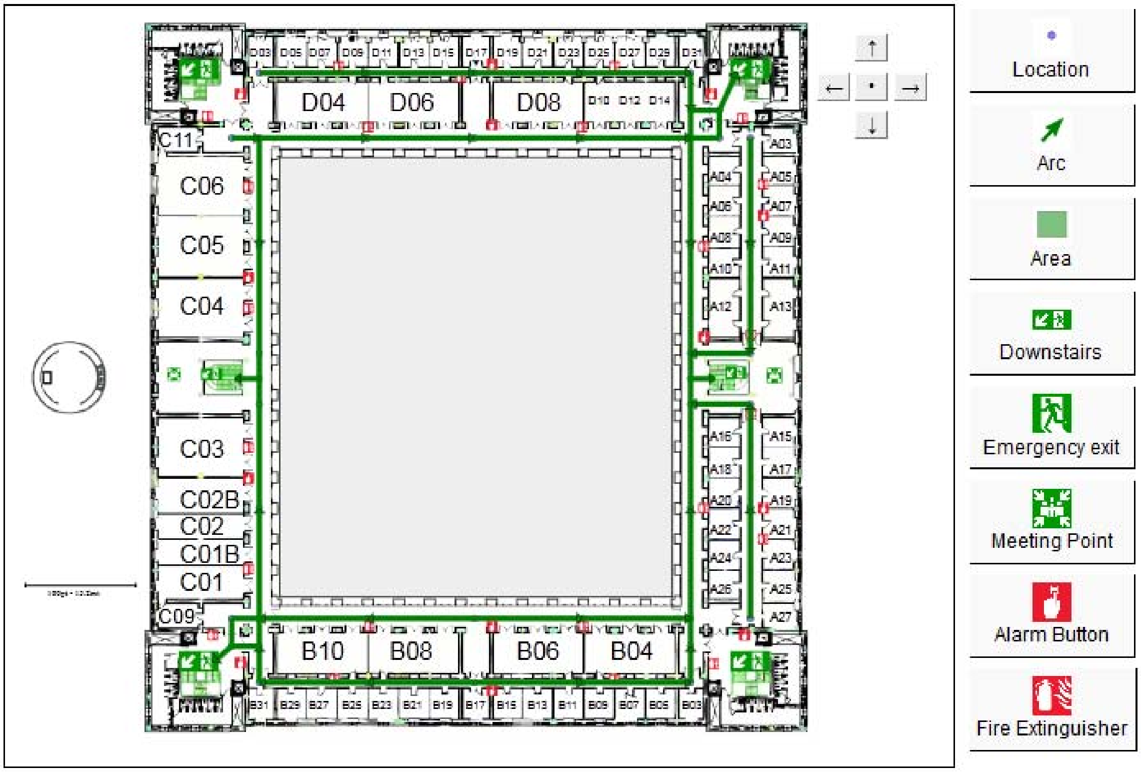


Figure 6.8: The definition of the emergency evacuation routes for a floor of the building through NERES

3. Considering the users' profiles, the system determines which evacuation routes are incompatible with their abilities (e.g. no stairs for people with motor impairments).

4. With the final set of possible routes, the system chooses the shortest one as the most appropriate one.

5. Once the route has been selected and in accordance with the capabilities of the devices, the users' profiles and the emergency context, the evacuation route is notified with an appropriate visualization mode.

NERES provides three different visualization modes to present both instructions and maps of evacuation routes. The first one is *Text-Only* view that displays a list of steps with a short description for each one. The second mode is *3D* that shows an actual photo of the indoor location for each step of the route with an arrow to indicate directions to follow. The last one, called *Map*, shows the entire route on the map of the building with a short description of each step. For instance, in case of a fire event in a building the smoke could limit the vision. In such conditions, a 3D visualization mode (e.g. images of the environment) could help users in orientating themselves and reaching the exit. In the same situation, if the user has a visual impairment, she should receive a Text-Only description of the evacuation instructions to be read with a text-to-speech tool.

6.2.2 iNERES

The iNERES component is a mobile application that serves as client interface for receiving and visualizing the evacuation routes. Moreover, it allows to send additional details about the context and to establish a bidirectional communication channel with the Command Post (i.e. the emergency operator in charge of managing the evacuation procedure). To do this, iNERES exploits current technologies such as Wi-Fi fingerprinting, pattern recognition, augmented reality, chat service, and push notifications. Using this mobile application along with CAP-ONES and NERES, users can receive personalized alert notifications and updated evacuation information about available routes. This information can help affected people in escaping and heading to the nearest safety place. In addition, the users can communicate with the Command Post not only for requesting help but also for contributing as witnesses on the site.

The main idea behind the development of iNERES is that an increasing number of users has a portable device that can be used as a helpful support during emergency situations. Figure 6.9 shows the detailed architecture of iNERES and NERES.

The notification generated by CAPONES is received (part A in Figure 6.9) depending on the personalization of the communication channel (e.g. sms, mms, email or push notification). Successively, iNERES retrieves the position of the user and send the location data to NERES (part B in Figure 6.9). There are four different way to do this:

1. default location from user profile;
2. fingerprinting mechanism based on Wi-Fi triangulation;
3. pattern recognition mechanism to recognize the building tags (e.g. office number label);
4. current location typed or selected by user.

The last three location modes are shown in Figure 6.10. To simplify the user interaction, the default location method uses the Wi-Fi fingerprinting mechanism

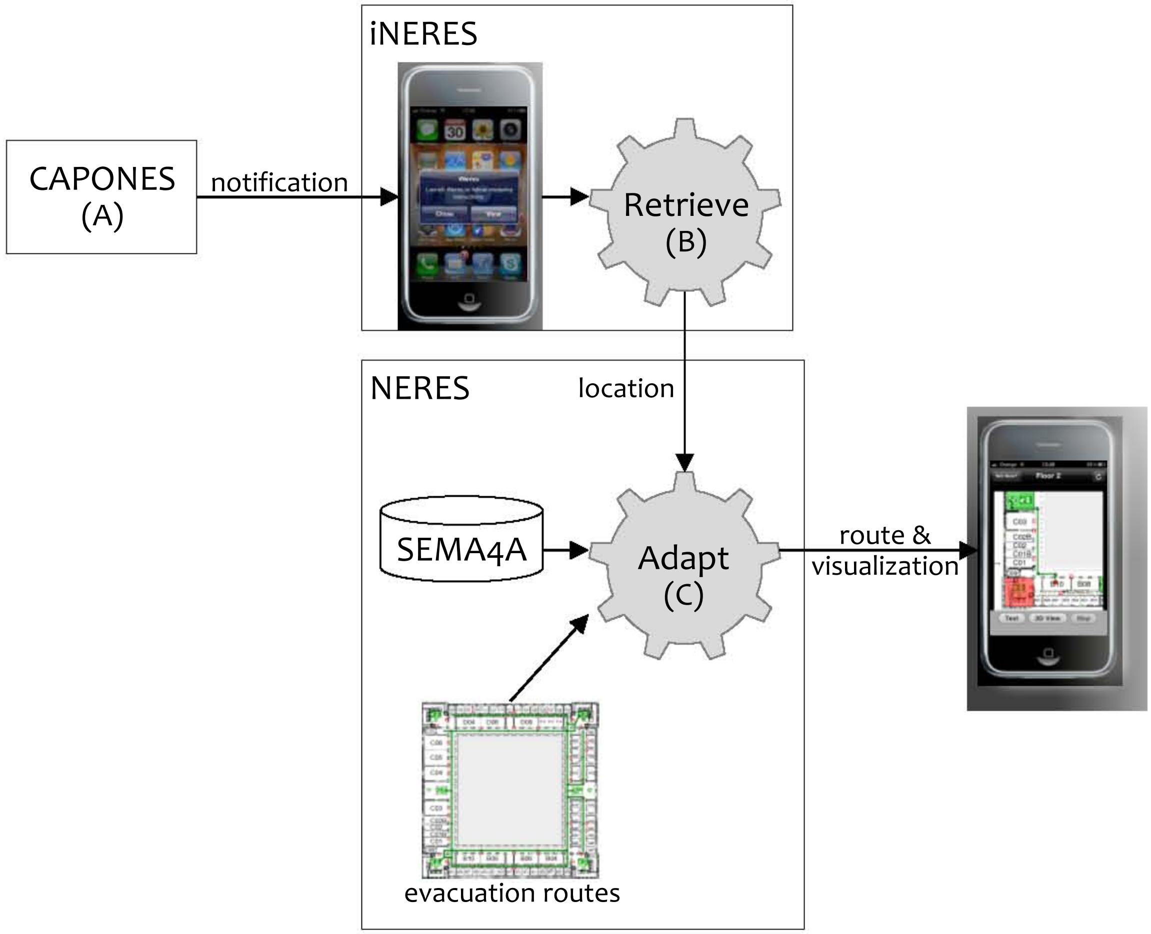


Figure 6.9: The detailed architecture of iNERES and NERES: (A) CAPONES sends the alert notification to iNERES; (B) iNERES retrieves the user's location and sends it to NERES; (C) NERES queries SEMA4A for adating the evacuation route and the visualization mode

that does not require any user input. This mechanism is based on the method developed by Bolliger in (Bolliger, 2008). This method creates fingerprints of each location by scanning available Wi-Fi networks and measuring the signal strengths for each one, storing this data altogether with a corresponding label. This way, when a user's location is needed, the application creates a fingerprint and requests for the location that better matches it. If there is no Wi-Fi connection available, it is possible to use the other location modes through an available 3G network. In particular, the pattern recognition mechanism requires to take a shot of the building room tag. Consequently, the location is retrieved by the back-end server running an

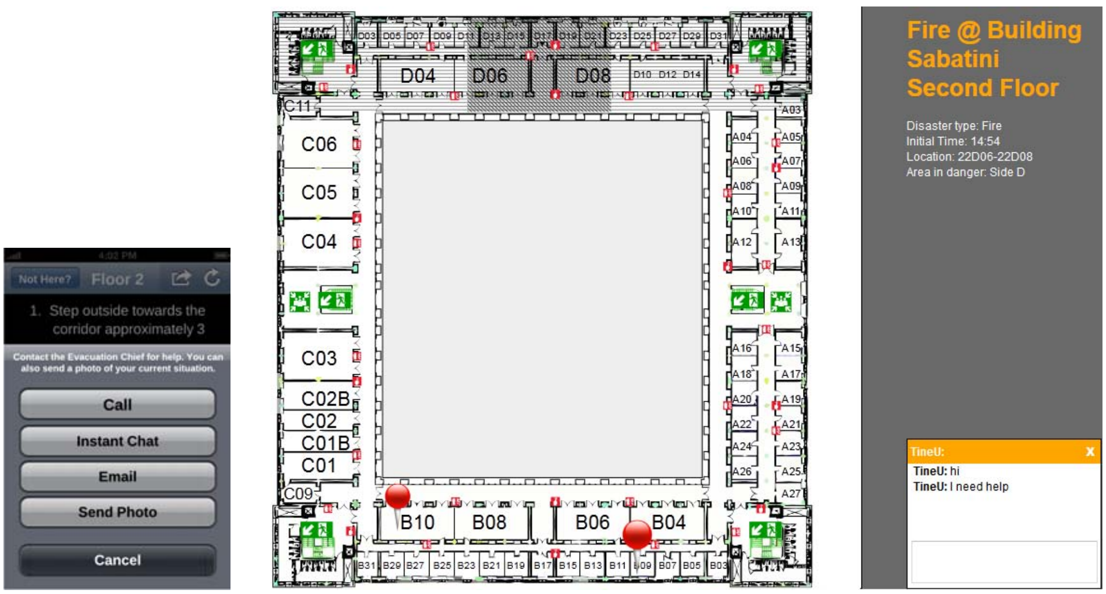
Optical Character Recognition (OCR) algorithm.

(a) Wi-Fi triangulation (b) Pattern recognition (c) User input

Figure 6.10: iNeres user's location modes

Once the user location data is computed, it is elaborated by the NERES component to select the most suitable evacuation route within the official evacuation plan (part C in Figure 6.9). Together with the route, NERES also provides a particular visualization mode among Text-Only, 3D and Map. Moreover, in iNERES another visualization mode is added: the augmented reality view. This interaction paradigm allows to overlay information and direction to the actual view of the device camera.

Concerning the bidirectional communication channel established between the Command Post and the affected people, this can be used in substitution of traditional calls to the global emergency number such as 911 or 112. Apart from the delay time needed for redirecting the phone call from the emergency centre to the Command Post, the use of smartphones gives the possibility to also send multimedia content. In this way, users can enrich their messages adding images of their position or any exceptional circumstance useful for the emergency operations. Figure 6.11 shows an example of the interaction mechanism between a user and the Command Post. The (a) image depicts different multimodal communication channels on iNERES while the (b) image shows the front-end application for the Command Post on NERES. In the application for the Command Post, there is an interactive map on the left with several information of interest such as meeting points, exits, affected areas by the emergency (darkest square filled with diagonal lines in the (a) image of Figure 6.11), unavailable areas (horizontal lines in the (b) image of Figure 6.11), location of users subscribed to CAPONES (thumbtacks in the (b) image of Figure 6.11). On the right, the chat mechanism with the users of the iNeres mobile application is open.



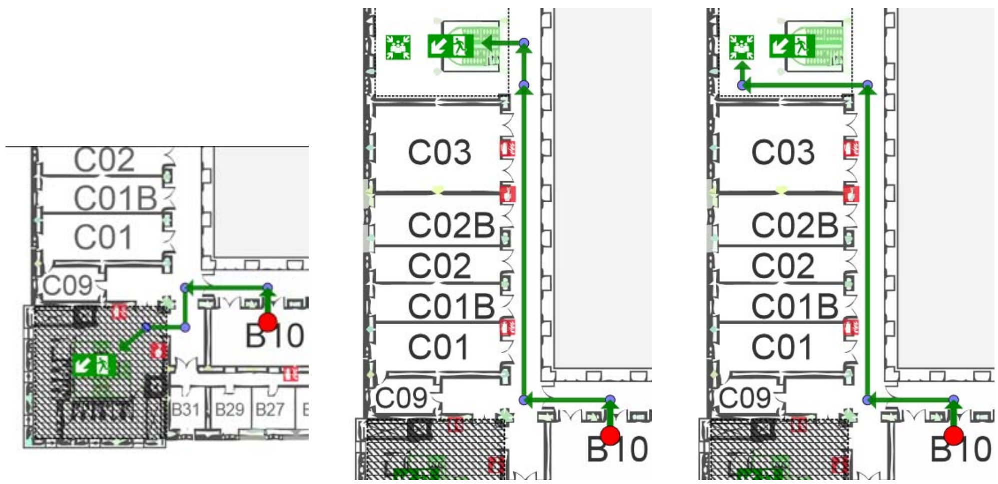
(a) (b)

Figure 6.11: The communication channel with the Command Post. (a) the iNERES interface. (b) the NERES interface

6.2.3 Usage of NERES

In order to understand how the NERES architecture works, in this section we are going to describe an example of its application. Consider an user with limited mobility subscribed to CAPONES. Her personal device allows to send and receive multimodal content (e.g. images or videos). The user receives from CAPONES an alert notification about a fire emergency in the building where she works. Moreover, an evacuation procedure is required to avoid personal damages. She launches the iNERES application that calculates her location (e.g. the office number 2.2.C01B) and sends a request to NERES for obtaining a personalized evacuation route according to her profile.

Considering her location, NERES identifies three potential routes with different ending points: (a), (b) and (c) in Figure 6.12. NERES verifies each route according to the contextual information of the emergency and detects that route (a) passes through a dangerous area (the square filled with diagonal lines in Figure 6.12 represents a dangerous area), therefore the route is discarded. After that, the system analyses the route (b) in Figure 6.12, which includes a stairway as ending location. Taking into account the user's profile and her motor impairment, she cannot go downstairs without an appropriate support. For this reason the route (b) is also discared. The last route ((c) in Figure 6.12) is selected as the most appropriate one because it has a meeting point as ending node where the user should receive assistance for escaping from the building.



(a) Crossing a dangerous area (b) Stairway ending point (c) Selected route

Figure 6.12: Potential evacuation routes according to user's location

Finally, the system considers both abilities of the user and capabilities of her device to determine an appropriate visualization mode. Considering that the user knows the building, the Map mode could help her in finding quickly where she has to go to receive assistance. At this point, NERES sends the personalized route with the selected visualization mode to the user through the iNERES application. Finally, the user receives the route with the Map view as shown in the image (c) of Figure 6.13. Moreover, the user has the possibility to change the visualization mode choosing among the others ((a), (b) and (d) in Figure 6.13).

(a) Text-Only (b) 3D (c) Map

(d) Augmented Reality

Figure 6.13: The visualization modes of the evacuation routes in iNERES

6.3 EMERGENSYS

The last use case we are going to present as example of the applicability of SEMA4A is EMERGENSYS. The EMERGENSYS project aims at improving the communication between citizens and emergency operators in order to enhance their collaboration during the response phase of the emergency management process. On the one hand, citizens cooperate sending data about their position and their profile to the command centre. On the other hand, agents deal more efficiently with the emergency response knowing the number of people involved and their situation. In particular, a notification mechanism based on SEMA4A is provided to send personalized instruction to the citizens. The personalization refers to adapting the evacuation routes to the users' profile and the characteristics of the emergency.

Within this scope, a two-layer architecture has been defined (see Figure 6.14): the *CENTRAL* and the *APP*.

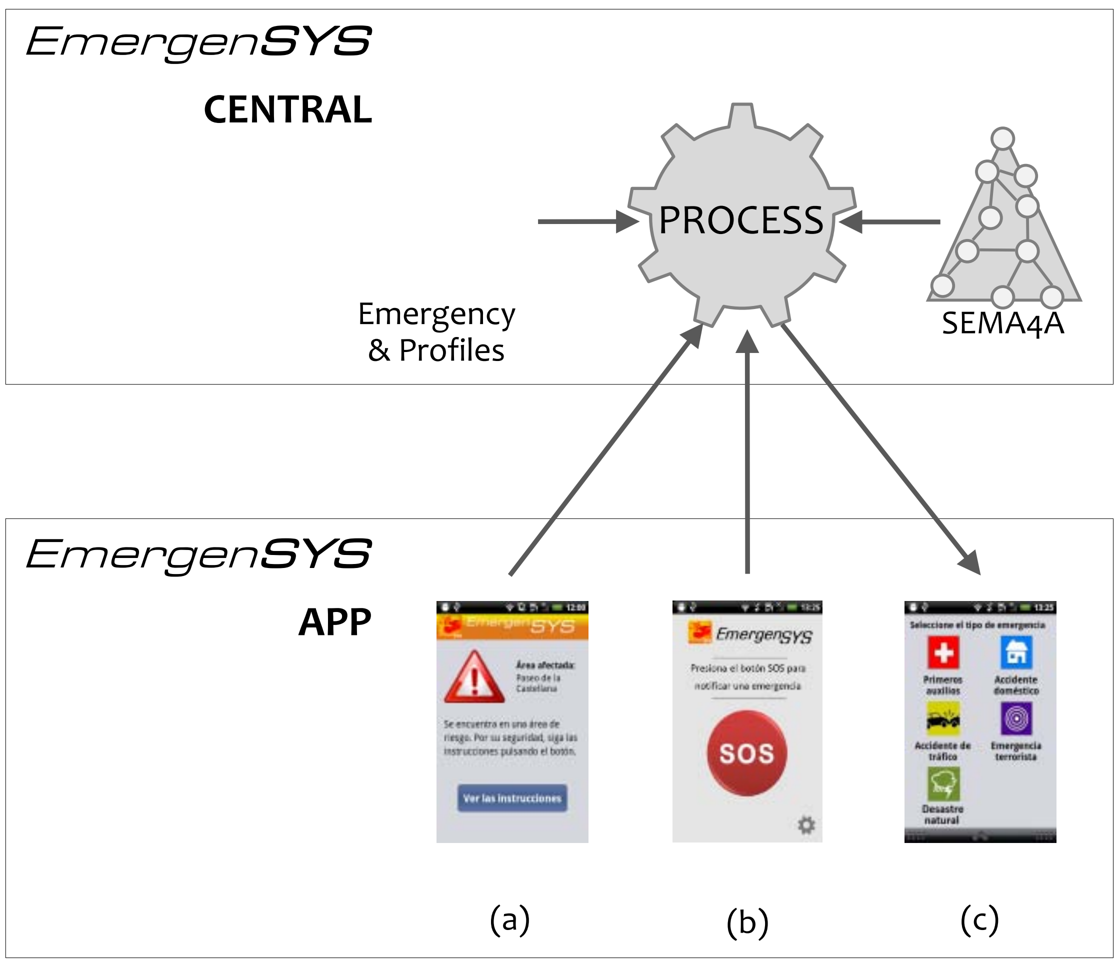


Figure 6.14: The architecture of the EmergenSYS project with the two layers: the CENTRAL and the APP

The *CENTRAL* layer represents the operation centre where the decisions about the emergency management are made by the emergency managers and operators. It is composed by three elements:

- The *Emergency & Profiles* is a database with the received emergency alerts about both past and current events. Also the profiles of the subscribed users are stored here. Each profile contains several information, like the abilities, the preferences and any other special needs.
- The *Process* groups the following activities performed by the operators:
  - Adapting the available information about the emergencies and the evacuation procedures depending on the profiles of subscribed users;
  - Sending adapted information to subscribed users to alert them about current emergencies and evacuation procedures;
  - Receiving information about incidents or emergency situations from common citizens and making a decision about the response activities to perform.
- The *SEMA4A* ontology is used by the *Process* for adapting collected information about the emergencies and the evacuation procedures based on the profiles of subscribed users.

The *APP* layer is in charge of the interaction with the citizens through the development of two different kinds of mobile applications. The first one is for notifying critical information from the operation centre to the citizens, while the second one is from collecting data from the citizens to the operation centre. In the following subsections, we are going to describe each one of these directions.

6.3.1 From the operation centre to the citizens

The first application is for receiving the emergency alerts sent by the operation centre (see part (a) in Figure 6.14). Notified information depends on the geographical position of the citizen. If she is not in the area where the emergency occurs, she would receive just a description of the emergency. Otherwise, if she is in dangerous, she would be notified with also an evacuation route for reaching the nearest safety point. The SEMA4A ontology is used for implementing the personalization of the route and the used mode for visualizing it depending on her abilities and needs (i.e. the *Process* element of the *CENTRAL* layer). In particular, there are different visualization modes defined into SEMA4A. The default visualization mode is the most suitable one considering the user's profile and the characteristics of the emergency. The available ones for the scope of this project are the following:

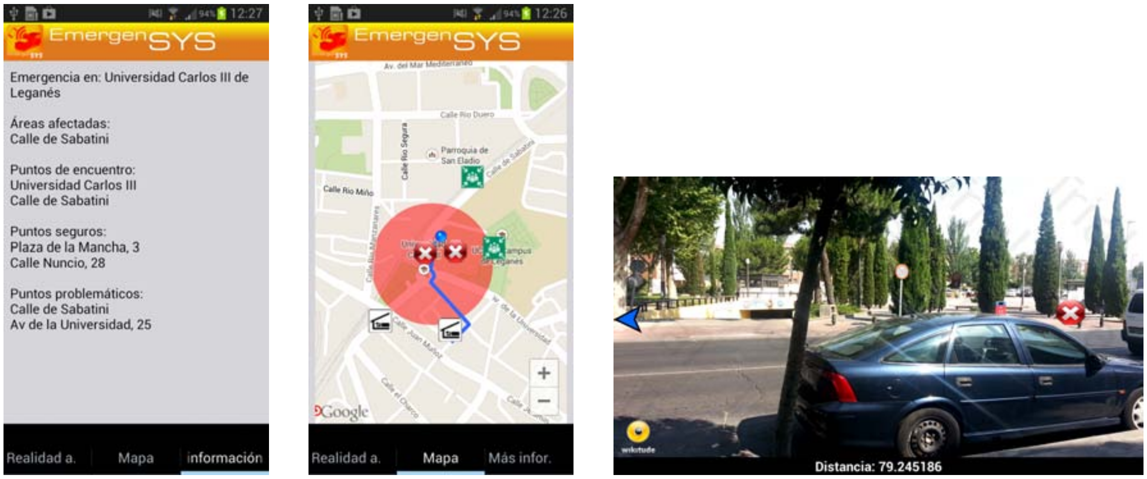
- The first mode is the textual description of the instructions to follow.
- The second mode is a map of the situation where the dangerous areas are represented with red circles, the points of interest (i.e. shelter, hospitals, meeting points or interrupted roads) with representative icons and the route with blue lines.
- The third mode is the augmented reality that uses the view from the camera of the mobile phone designing the nearest points of interest and directional arrows to guide the citizen.

As an example of how this application works, consider a bomb removal scenario. In a populated urban area, an unexploded bomb from the second World War is localized. In response to this situation, the emergency operators start an evacuation procedure in order to guide all people in the area to a safe place. To do this, it is crucial to keep the affected citizens informed about the situation, facilitating instructions for escaping and notifying about which are the dangerous areas and the interrupted roads.

The proposed architecture (see Figure 6.14) responds to this need providing the operation centre with a notification mechanism able to send information and evacuation routes adapted to the profile and in particular the geographical position of involved citizens. In particular, the system retrieves the geographical position from the users' devices to determine if they are in the crisis area. If they are, they receive instructions for the evacuation. Otherwise, they receive general information about the situation. The notified evacuation route as well as the chosen visualization mode (see Figure 6.15) take into account the abilities or the particular needs of the user through the SEMA4A ontology. A person with a visual impairment could need help for escaping and for this reason, she could be notified with a route for reaching a meeting point where an assistant is waiting for her. Moreover, the instructions are visualized as a textual description that her phone can read through a text-to-speech tool.

6.3.2 From the citizens to the operation centre

The second application is used by the citizens to notify the operation centre about incidents or any other exceptional circumstances both as victims or witnesses. This service has been developed in substitution of the traditional emergency call and it has two versions. The first one is a panic button (see Figure 6.16) specific for people with special needs (i.e. elderly, functional or contextual disabilities). Pushing the button, the application collects useful data from the mobile phone and



(a) Text Only (b) Map (c) Augmented Reality

Figure 6.15: The visualization modes for the received evacuation routes

send them to the operation centre. Moreover, knowing the profile of the users subscribed to this service the operation centre can use the SEMA4A ontology to infer personalized response actions when they receive the alerts.

Figure 6.16: The panic button version

The second version is more complex than the previous one and offers the possibility to collect more detailed information from the citizens. For this reason, it has been structured following the questions usually asked by the operators during the emergency calls. The collected data are listed:

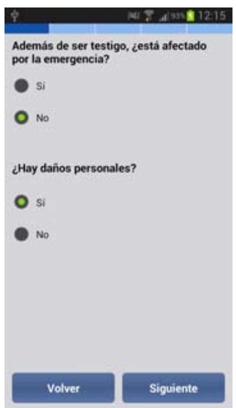
- Name, surname, telephone number and geographical location of the citizen are retrieved automatically from the mobile phone if available;
- Kind of notified incident;
- Geographical location of the incident, automatically retrieved by the mobile phone. The citizen has also the possibility to customize it choosing a different one on the map;
- If there are or not victims;
- Multimedia resources, including audio recordings, photos and videos.

In order to better explain how this application can be used, consider a car accident happened in a central street of a small village. The car impacted against a guardrail and only the car driver has been involved. The driver gets down the car and then falls down unconscious. A witness wants to alert the operation centre through the proposed application.

In Figure 6.17, the different steps for gathering information are shown. First of all, the witness selects the kind of emergency (i.e. Traffic Accident), choosing among First Aid, Domestic Accident, Traffic Accident, Criminality and Natural Disaster (see part (a) in Figure 6.17). After that, she is asked to specify if she has suffered any damage or there are other affected victims, answering that she is safe but there is an injured person (see part (b) in Figure 6.17).

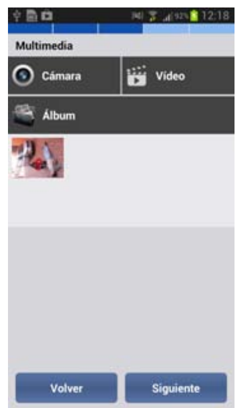
Successively, she has the possibility to add a textual or audio description (see part (c) in Figure 6.17) and a multimedia resource, like photos, videos or audio recordings. In this case, she decides to take a photo of the victim (see part (d) in Figure 6.17). Finally, she specifies the position of the incident in the map, leaving the one automatically retrieved by the application (see part (e) in Figure 6.17), and send the message to the operation centre. The operation centre receives the information from the witness and analyses it for finding the most appropriate response to the event. Taking into account that the operators are trained to quickly understand the conditions of a victim, the photo represents an helpful support for making decisions.

(a) Kind



(b) Victims

(c) Description



(d) Media

(e) Map

Figure 6.17: The screens for collecting data about the incident

Chapter 7

Conclusions

7.1 Revisiting the Research Methodology

To discuss the conclusions for this research work, we are going to revisit the Design Science Research Methodology by Hevner and Chatterjee (Hevner, 2007). The methodology has been already followed for analysing the related literature, defining the research question (see Chapter 3), and proposing the solution (see Chapter 5). In Figure 7.1, the final phase of the methodology is depicted.

The developed artefact is an ontology called SEMA4A (Simple EMergency Alerts 4 [for] All). The ontology models four domains of interest: accessibility, technology, emergency and evacuation. The ontology is the proposed solution for establishing a deep correlation among three factors (i.e. the *user*, the *context of use* and the *situation*), as stated by the research question.

The design cycle is based on the application of well-known techniques for developing ontologies. These techniques aim at identifying a complete representation of an articulated knowledge area in form of concepts and relations among them. The consistency and the completeness of this representation have been verified within the evaluation phase. To do this, we have performed both a quantitative and a qualitative evaluation. For the qualitative evaluation, we have interviewed several international domain experts asking for the the quality of the knowledge representation.

In order to test the pointed out hypotheses (see Chapter 1), we were interested in both the quality and the applicability of SEMA4A. While the quality has been verified by the evaluation phase, for the applicability, three notification tools for evacuation procedures and emergency information have been developed. All of

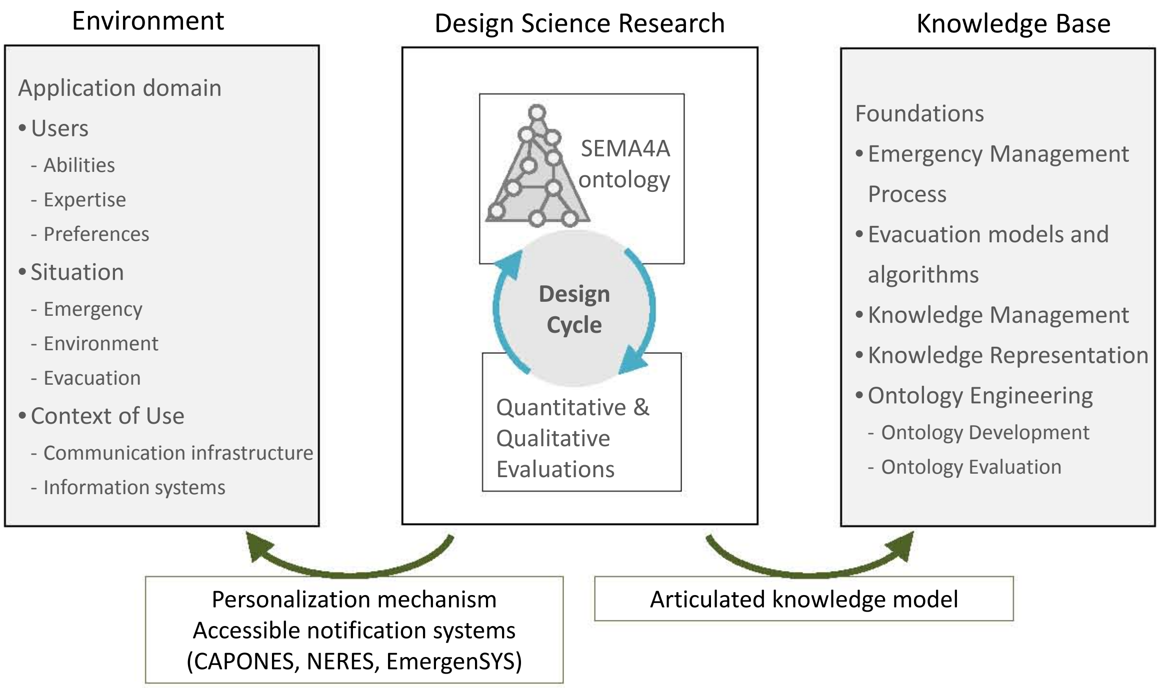


Figure 7.1: The output phase of the Design Science Research Cycle by Henver and Chatterjee (Hevner, 2007)

them interoperate with SEMA4A for making the notifications accessible taking into account the users' profile, the emergency, the evacuation procedures and any other exceptional circumstances.

The development of this research work have highlighted several results, not only as effective contributions for the emergency management area and the knowledge modelling, but also lessons learnt and limitations that would be considered for proposing some future works, as discussed in the following sections.

7.2 Contributions and lessons learnt

The main contribution of this thesis is the SEMA4A ontology that provides a conceptual basis to develop IT tools for making notifications accessible for every user, context of use and situation. It is an interoperable knowledge base that existent tools in the area of emergency and evacuation management can use for answering to the following questions:

- Which is the most useful information about the emergency for alerting adequately the users?

- Which is the most effective channel for establishing an effective communication between the users and the operation centre? In this case, it is crucial to consider both the users' devices and the infrastructures still available in the emergency situation?

- Which is the most useful evacuation route considering the official evacuation plan, the characteristics of the emergency, and the abilities or the special needs of the affected users?

From a practical point of view, the second contribution is about the interoperability. The development of the three notification systems (i.e. CAPONES, NERES and EmergenSYS) has highlighted the crucial role of the interoperability and the personalization for managing and organizing a critical situation. In fact, this kind of systems has to manage different activities depending on the characteristics of the event. Consequently, they would require a modular architecture where each module is in charge of a different functionality. For this reason, SEMA4A as the module for the personalization of the alert notifications has been coded with a standard language in order to interoperate easily with the other ones.

From a theoretical point of view, SEMA4A represents an interesting contribution for the area of Ontology Engineering due to three main reasons.

Firstly, in literature there are not any other examples of knowledge representations for modelling the four domains of interest (i.e. accessibility, technology, emergency and evacuation). This means that SEMA4A can be considered as a base for future research works in the same area.

Secondly, the analysis of the most common techniques for building ontologies has shown that it requires a detailed characterization of the domain to model. For this reason, three different approaches have been selected for designing SEMA4A:

- Reusing existent ontologies in the domain of accessibility;

- Natural language process based on the WordNet dictionary with two taxonomies about technology and emergency as starting points;

- A natural language process based on the two statistical functions *Domain Relevance* and *Domain Consensus* applied to a set of documents about evacuation procedures, plans and models.

Each one of them required the implementation of a specific algorithm involving notions from the disciplines of Artificial Intelligence and Statistics. For example, the third one employs two functions based on a deep understanding of two statistical measures: entropy and probability.

Thirdly, in order to evaluate the quality and the validity of an ontology it is crucial to involve the domain experts. For this reason, we have conducted the sets of interviews proposing the relations defined in the ontology in form of a questionnaire. The first one was with the experts in accessibility and emergency, and the second one was with the experts in evacuation procedures. Obtained feedbacks showed a great interest in SEMA4A confirming its validity as representation for their areas of expertise. In particular, from an extensive analysis of the literature about ontology evaluation methods, we have found out that the validity of an ontology can be measured computing three functions: coverage, accuracy and precision. Their usage over the collected answers required also the implementation of an algorithm based on natural language processing techniques.

From the performed interviews, we have also learnt that the used questionnaire has to be easy to use and understand in order to make the experts feel comfortable. For this reason, while for the first interview we used an Excel table, for the second one we have developed an ad-hoc visualization tool where the ontology has been shown as a navigable map.

Finally, the research value of described contributions has been proved also by several publications related to the scope of this thesis ((Onorati et al., 2009), (Onorati et al., 2010), (Onorati et al., 2011)), the SEMA4A ontology ((Malizia et al., 2008), (Malizia et al., 2010)) and its use cases ((Malizia et al., 2009a), (Malizia et al., 2009b), (Aedo et al., 2012), (Díaz et al., 2013)) in international journals and conferences. Moreover, both the ontology and the three use cases have been developed collaborating within the following research projects.

- UIA4SIGE, Usability, Interoperability and Accessibility of Information Systems for Emergency Management, funded by the Spanish Ministry of Science and Innovation.

- EmergenSyS, Integrated System for Mobile Crisis Management Complex, funded by the Spanish Ministry of Economy and Competitiveness under INNPACTO programme in collaboration with the industry partners Planet Media and Collaborative S.A.

7.3 Limitations and future works

Within this research work, we have identified also several limitations that can be taken into account for planning the future works.

First of all, the choice of developing an ontology is for establishing a correlation among three factors: the user, the context of use, the situation. This correlation is represented as a conceptualization of four domains of interest (i.e. accessibility, technology, emergency and evacuation). In order to interoperate with SEMA4A and make the notifications accessible, the emergency systems have to associate the ontology concepts with the information about the real scenario. For example, if a fallen tree is interrupting one of the evacuation routes, this can be avoided through the relation defined into SEMA4A <route, cannot contains, damage>, where the damage is the interrupted road. This limitation depends on the kind of information managed by the particular system. A way to solve it would be to add a module to the proposed architecture for standardizing the data in input and make the needed association.

Another limitation is related to the results obtained from the evaluation phase. In average, the SEMA4A ontology covers almost the 70% of the considered knowledge. This is due to several factors, as the used techniques for building it and the characteristics of the involved domains. Taking into account that the aim of this work focuses on establishing a deep correlation among four different knowledge areas (i.e. accessibility, technology, emergency and evacuation), this limitation does not influence the effectiveness of the proposed solution. Nevertheless, we could exploit the development of other use cases in order to confirm this consideration.

Furthermore, future works will include studying the possibility of applying the proposed solution to other scenarios. Not only the notification mechanisms, but also the other activities of the emergency management process could take advantages from the offered personalization mechanism. For example, a tool in charge of defining the official evacuation plan could infer from the ontology the special procedures to take into account for the vulnerable groups. Another interesting example concerns the preparedness phase and in particular the training of the emergency operators. From SEMA4A, possible emergency and evacuation scenarios can be extracted and presented to be solved by the operators.

Finally, other applications of SEMA4A would require to extend and adapt it to new requirements. For example, in case of developing notification mechanisms for new interaction paradigms (e.g. pervasive devices as wearable or touch sensitive tools), additional knowledge about them are needed within the communication class of concepts. To do this, there are techniques for evolving the ontology, its schema and structure as proposed by Noy and Klein in Noy and Klein (2004). Also in this case, the involvement of experts is crucial. Moreover, the extension would take advantages of the standard language used for coding SEMA4A.

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