An Ontology for Fire Building Evacuation

Joaquim Neto, António Jorge Do Nascimento Morais,
Ramiro Gonçalves and António Coelho

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Joaquim Neto [0000-0003-1228-1236] [12], A. Jorge. Morais [0000-0003-2224-1609] [13], Ramiro Gonçalves[0000-0001-8698-866X][4], António. Leça Coelho[2]

[1] Universidade Aberta, Lisboa, Portugal
{jaqf.neto@gmail.com, jorge.Morais@uab.pt}
[2] Laboratório Nacional de Engenharia Civil, Lisboa, Portugal
{jfn@lnec.pt, alcoelho@lnec.pt}
[3] LIAAD - INESC TEC
[4] UTAD (Universidade de Trás-os-Montes e Alto Douro

Abstract. Guiding the building occupants under fire emergency to a safe place is an open research problem, and finding solutions to address the problem requires a perfect knowledge of the fire building evacuation domain. The use of ontologies to model knowledge of a domain allows a common and shared understanding of that domain, between people and heterogeneous systems. This paper presents an ontology that aims to build a knowledge model to understand the referred domain better and help develop more capable building evacuation solutions and systems. The herein proposed ontology considers the different variables and actors involved in the fire building evacuation process. We followed the *Methontology* methodology for its developing, and we present all the development steps, from the specification to its implementation with the *Protégé* tool.

Keywords: Fire Building Evacuation, Ontology, Knowledge Model, Ontology Development, Fire Emergency

1 Introduction

This paper is part of our ongoing doctoral thesis that aims to develop and study a multi-agent recommender system capable of real-time guiding the occupants to a safe place [1]. The proposed solution considers an ontological model to adequately support the interoperability between the different actors involved in the building evacuation process. The purpose of this ontology is to build a knowledge model that can contribute to a better understanding of that domain and help develop solutions or systems to address the fire building evacuation problem.

Section 2 presents some of the relevant research works that propose ontologies to model knowledge in emergency areas. Section 3 briefly introduces the ontology concept and describes the main steps in developing an ontology. Section 4 presents the work developed to build the ontology step by step, and section 5 describes the ontology evaluation process. Finally, in section 6, we write the conclusions and future work.

2 Ontologies for the building emergency domain: Related work

Many research works have been proposed ontologies to represent knowledge in the area of emergencies. Here we will highlight some of those relevant research works, particularly addressing the fire building emergency field. In their paper, [2] present the ontology SEMA4A, which aims to include information sharing and support the interoperability between systems and between people in an emergency. The ontology provides knowledge according to three domains: accessibility guidelines, emergencies and communication technologies. Later on, based on SEMA4A ontology and focusing on the evacuee's notification about safe places and evacuation routes, [3] develop an extension of the SEMA4A ontology, thus compiling a fourth area related to evacuation. In their article, [4] present an ontology that defines the concepts of fire control, and the relationship between these concepts, from the community's perspective, defining how the members of a community come together to control a fire. Intelligent emergency response applications must interpret and filter relevant information from a wide range of heterogeneous data. To support the development of that kind of applications, [5] present the ontology "Emergency Response Ontology". [6] present the EMERGEL ontology (Emergency ELements), developed in the scope of the DISASTER project (Data Interoperability Solution in Emergency Reaction Stakeholders), co-financed by the EU. The EMERGEL ontology is an ontology that contains knowledge and concepts related to emergencies. In its article, [7] presents the EmergencyFire ontology, whose scope is to share knowledge of the domain of fire emergency response in buildings. The ontology aims to contribute to the organisations' tactical and strategic plans to respond to fire emergencies in buildings.

3 Ontologies: Methodological Approaches

According to Gruber [8], in computing and information science, the term ontology refers to an artefact designed to model knowledge about a domain, be it real or imaginary. According to the same author, in the 1980s, the term was adopted by Artificial Intelligence (AI) researchers, used to refer to a theory of a modelled world or a component of knowledge systems. According to [9], it is possible to see multiple and contradictory definitions for ontology in AI literature. In a widely cited article, [10] defines ontology in the context of AI as an "explicit specification of a conceptualisation", in which objects, concepts or other entities, as well as the relationships that exist among them, are used to represent knowledge within a domain.

As referred by [11], ontologies provide a common and shared understanding of a domain to help communicate between heterogeneous systems and people, consisting of a set of terms representing concepts (hierarchically organised) and some specification of its meaning. Ontologies are also promoters and facilitators of interoperability between information systems, intelligent processing by agents, or the sharing and reuse of knowledge between systems.

Although the comparative study of the different methodologies used in the development of ontologies is not within the scope of this paper, it is essential to mention the most representative and commonly used ones [11]: TOVE [12], ENTERPRISE [13] and METHONTOLOGY [14]. Another methodology widely followed is the "Ontology Development 101" [9].

Concerning the ontology development, and independently of the methodology, five stages may be identified in the life cycle developing of an ontology [14] [11].

- The first stage is the ***specification stage***. It is crucial to identify the objective and scope of the ontology. The following answers must be addressed: What is the domain to be covered by the ontology? Why build the ontology? What are the intended uses? What kind of answers should the ontology give?
- Once the ontology's objective and scope are defined, the ***conceptualisation stage*** follows. The ontology is described through a conceptual model to meet the specification defined before. It consists of concepts in the domain and relationships between those concepts (using mind maps, for example).
- The ***formalisation*** is the third stage in the development life cycle of an ontology. A formal model is constructed from the conceptual model of the previous stage. Concepts are generally defined through axioms that restrict possible interpretations to the meaning of those concepts.
- The fourth stage is the ***implementation*** of the previously formalised ontology in a knowledge representation language.
- The last stage refers to ***maintenance***, during which it is essential to update and correct the implemented ontology.

Also, according to [14] [11], three other activities should also be considered during the whole life cycle:

- ***Acquisition* of knowledge** about the domain, whether using elicitation techniques, listening to specialists or consulting the relevant bibliography.
- Technically ***evaluate*** the ontology's quality, namely using tools already available on the Web.
- ***Documentation***: Registration of what is being done, namely through the annotation and description of the terms represented in the ontology, in order to make it clearer to understand, as well as to facilitate maintenance and future reuse.

4 Building an Ontology for Fire Building Evacuation

To develop the ontology presented here, we adopted the METHONTOLOGY development methodology. The development process followed four main steps, already described in a generic way in the previous chapter: i) specification, ii) conceptualisation, iii) formalisation, and iv) implementation. During the development process, the activities carried out were also supported by acquiring and updating knowledge of the domain under study. We document and annotate the terms, concepts and relationships represented in the ontology and technically evaluate it.

4.1 Specification stage

The specification stage is a step of particular importance, as it is time to define the domain, scope and purpose of the ontology. The literature review carried out allowed the identification of different ontological approaches in treating fire emergencies in buildings. We have approaches that focus on the response of the different actors involved in emergencies; approaches that focus on fire control knowledge; and other approaches, whose purpose is to model knowledge about fire safety, including the building evacuation problem. It is within the scope of the last type of approaches that we develop our ontology. Thus, our focus is the knowledge modelling of the building evacuation process, considering all the variables involved.

Follows from the above referred that the domain of ontology fits the building evacuation under fire emergency. As for the second question, the purpose is to represent knowledge about the evacuation of buildings, considering the different variables involved in the fire building evacuation process. For future use of the ontology, we highlight the ability to strengthening and consolidating knowledge about the domain of evacuation in buildings under fire emergency, as well as a support for the development of evacuation systems and applications, namely concerning the interoperability between the different actors involved in an evacuation process. Regarding the answers that the ontology should provide, we consider a set of competency questions [12] that help in the ontology's specification and scope and test the ontology at the evaluation stage.

We identify a set of competency questions based on Portuguese legislation and regulations[1] and the document of the Autoridade Nacional de Emergência e Proteção Civil (ANEPC) [15], as well as in the feedback of experts in the field. We present those competency questions and the most relevant aspects of the responses in Table 1.

From the above mentioned and, according to the competency questions table, we can better define our ontology's scope and objective, which we do in table 2.

4.2 Conceptualisation stage

At this stage, we will use the before defined specification and requirements to describe the ontology through a conceptual model, consisting of a set of concepts or terms and the relationships between them. The knowledge acquired in the specification phase, which we summarise in tables 1 and 2, can also be represented through the conceptual map of Fig. 1, built using the *mindomo*[2] framework. To build the conceptual map, we start with three main terms, *Building*, *Occupant* and *Fire*, that immediately follow what we have already defined as the ontology's domain and scope.

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[1] Decreto-Lei n.º 220/2008 de 12/11 - Regime Jurídico da Segurança Contra Incêndios em Edifícios (SCIE)

[2] www.mindomo.com

Competency Questions	
Questions	**Answers**
How to detect the start of the fire?	Depending on the type of building, the law requires installing fire detection systems, that may be triggered automatically by sensors or manually by people in the building.
How to transmit the alarm to the building occupants?	They are notified through audible, sound or previously recorded messages, or visual alarms: i) Local alarm (directed to occupants of a part of the building), ii) General alarm (for the general evacuation of the building); iii) Restricted alarm (only for security personnel).
Who are the occupants? How do they behave in an emergency?	Occupants are people inside the building during evacuation. The evacuee's behaviour depends on age, gender, mobility and psychological characteristics. Also crucial is the evacuee's knowledge of the building and familiarisation with evacuation drills.
What is the topology and functionality of the building? Where are the safe zones located? What is the building's capacity?	The answers to these types of questions must are in the internal emergency plan. That plan includes the action plan, evacuation plan, safety instructions, emergency plans and the organisation to be adopted in case of emergency.
How is the building evacuated? What are the evacuation routes, and are they identified? What type of emergency signage?	The evacuation must take place following the building's organisation and management of fire safety, which includes the internal emergency plan, and all prevention procedures and plans, in case of emergency. The emergency signs must respect the building's emergency plan. Occupants follow emergency signs and seek the support of building security staff, firefighters and the police officer.
What are the types of hazards?	The hazards are toxic gases, smoke, temperature to which the occupants are subject, high density of occupation, which condition the occupant's behaviour, and the building's evacuation, leading to blockage and congestion of the evacuation routes.

Table 1. Competency questions and answers

Ontology specification and requirements	
Ontology domain:	The domain is the evacuation of buildings under fire emergency.
Ontology goal:	To develop a knowledge model about buildings' evacuation under fire emergency.
Ontology contribution:	• Provide a knowledge representation about the domain of evacuation of buildings under fire emergency; • support the development of fire evacuation applications and systems.
Answers that the ontology should give:	• How is the start of the fire detected? • How to notify the building's occupants? • What is the impact of occupant behaviour? • What are the types of hazards? • How to identify evacuation routes? • How to find exits and safe locations? • How are occupants guided to a safe place?

Table 2. . Ontology specification and requirements

4.3 Formalisation and implementation stages

Throughout this section, we transform the conceptual model into a formal model, and we implement the formalised ontology in a knowledge representation language. For the implementation, we used *Protégé* (Musen, 2015) (an open-source platform that provides a suite of tools to construct and describe ontologies), using the conceptual model previously defined to create the classes and object properties. From the terms, concepts and relationships described in the conceptual map of Fig. 1, we identify 52 classes and 57 object properties.

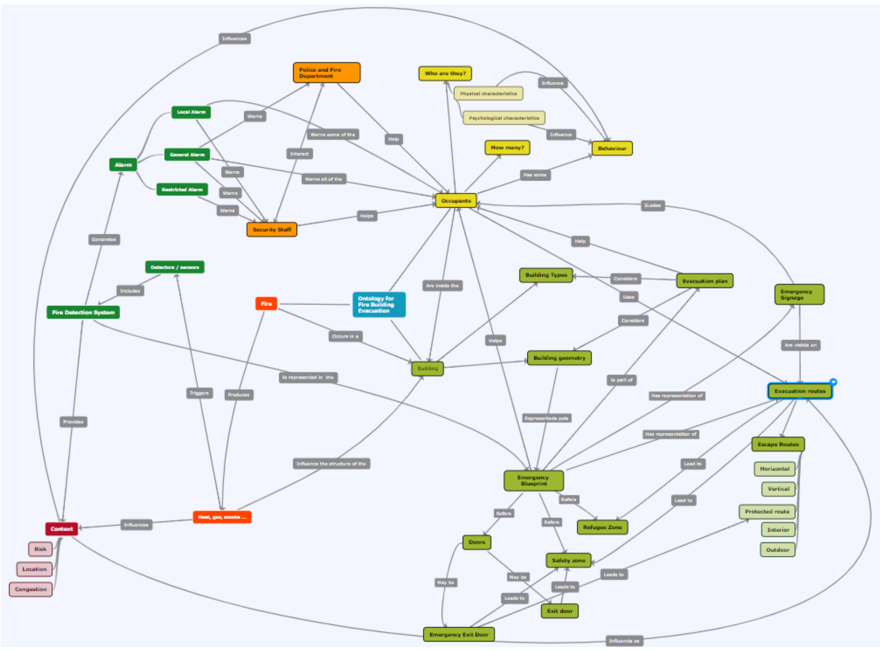

Fig. 1. Conceptual map of the Fire Building Evacuation Ontology[3]

Using *Protégé*, we create and describe the classes, subclasses, and the object properties that characterise the relationships identified in the conceptualisation stage. In Fig. 2, we exemplify this characterisation with the *AutomaticFireDetectionSystem* class, and a graphical representation is shown.

Object properties relate instances of two classes [16]. In Fig. 3, we present the example of the property *hasAutomaticFireDetectionSystemComponent*, that defines a relationship between an individual of the class *AutomaticFireDetectionSystem* (domain) and an individual of the class *AutomaticFireDetectionSystemComponent* (range) establishing that an automatic fire detection system has components, represented by instances of the *ControlUnit*, *FireAlarm* and *SensorUnit* subclasses.

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[3] https://www.mindomo.com/mindmap/38f6214ddb874641b486f3fdc2a06f4a

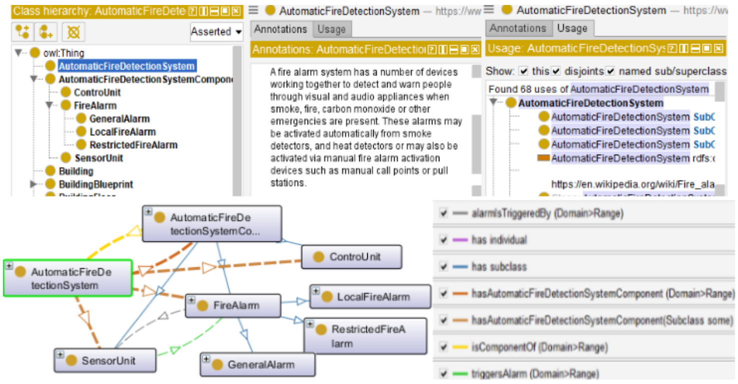

Fig. 2. Class representation on *Protégé*

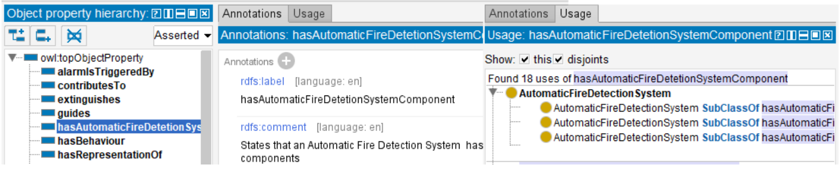

Fig. 3. The property *hasAutomaticFireDetectionSystemComponent*

Datatype properties relate an individual of a class to a primitive value [16]. In Fig. 4, we show the example of the property *isFamiliarWithBuiding*, which relates an individual of the class evacuee to a primitive type Boolean.

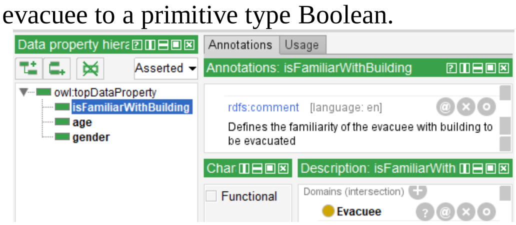

Fig. 4. Datatype properties in Protégé

5 Evaluation

According to [17] the evaluation of an ontology can be considered a technical judgment of its content with respect to a referential, and is an iterative process tha occur throughout all the development cycle of the ontology. The competency questions and the specification requirements, summarised in tables 1 and 2, embody that referential.

5.1 Technical evaluation

The technical evaluation deals with aspects related to ontology structure and architecture. It considers syntactic validation of classes and properties and aspects related to their documentation, to ensure an adequate understanding of the knowledge model represented by the ontology. The tests carried out with the tools referred above were completed with success and are available for consulting on the ontology URL[4].

In our research work, we use the Web tool, *Ontology Improvement Tool (V2)*[5], which provides other tools and services for ontology validation and improvement, namely concerning syntactic validation, with the RDF *Triple-Checker*[6], ontology consistency, with the *OOps! (OntOlogy Pitfall Scanner)*[7] [18] or to verify if the semantic Web data is correctly published and follows best practices[8,9,10], as is the case of the service provided by *Vapour*[11].

Concerning ontology documentation, we used *WIDOCO*[12] [19] a wizard that helps to document an ontology by identifying missing metadata, and by integrating other existing tools that allow ontology validation (with *OOPS*!), ontology terms documentation (with *LODE*[13]) and ontology visualisation (with *WebVowl*[14]). The *WIDOCO* tool produces the Web pages' ontology documentation, ready for publishing.

5.2 Evaluating against a referential

Another way of evaluating an ontology is their evaluation against a referential, embodied by the specification requirements and the competency questions, which must be answered by the ontology. It is an evaluation dimension that assesses whether classes, properties, and axioms can answer the questions and requirements, that were at the origin of the creation and development of the ontology. To assess whether the ontology proposed here answers the set of competency questions and requirements presented in tables 1 and 2, we query our ontology using the *SPARQL* language. Table 3 presents two examples, in which the *SPARQL* queries are complemented with a graphical visualisation provided by *Protégé's OntoGraf* plug-in.

6 Conclusion

By enabling a knowledge representation of a domain, ontologies provide a common and shared understanding for communication between people and heterogeneous systems. The ontology herein proposed aims to contribute to a better understanding of fire building evacuation domain. Another purpose of the knowledge model proposed here

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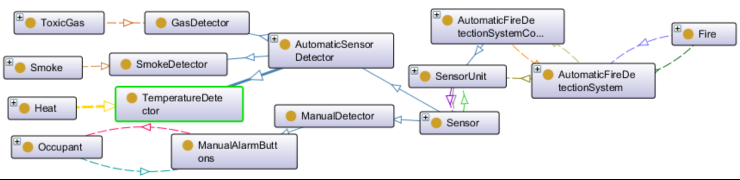
4 https://www.1000palavras.pt/ontology/fbevac/FireBuildingEvacuation-en.html
5 http://perfectsemanticweb.appspot.com/?p=ontologyValidation
6 http://graphite.ecs.soton.ac.uk/checker/
7 OOPS! - OntOlogy Pitfall Scanner! (linkeddata.es)
8 Linked Data - Design Issues (w3.org)
9 Best Practice Recipes for Publishing RDF Vocabularies (w3.org)
10 Cool URIs for the Semantic Web (w3.org)
11 http://linkeddata.uriburner.com:8000/vapour
12 http://dgarijo.github.io/Widoco/
13 https://essepuntato.it/lode/
14 http://vowl.visualdataweb.org/webvowl.html

is to support developing more capable building evacuation solutions and systems. This ontology considers the different and relevant variables and actors in building evacuation under fire emergency. The knowledge acquisition that supported the conceptual model was based on the Portuguese legislation and regulation analysis and expert feedback. The ontology development followed the METHONTOLOGY methodology and took place over several months, and we present the different stages of the development. For the implementation, we use the *Protégé* tool. The ontology was subjected to a technical evaluation, using tools available on the Web, and validated against the requirements and competency questions formulated in the specification phase. The ontology is publicly available at the URI: https://www.1000palavras.pt/ontology/fbevac/Fire-BuildingEvacuation-en.

As future work, the purpose is to direct our research work to deepen ontology by creating use cases and reusing the ontology proposed here to develop the ontological model [1].

Questions	Axioms
How is the start of the fire detected?	• (*Heat* or *Smoke* or *ToxicGas*) => *triggersSensor* => *Sensor* • *Occupant* => *press* => *ManuaAlarmButtons* • *ManuaAlarmButtons is-a subclassOf ManualDetector* • *ManualDetector is-a subClassOf* Sensor • *Sensor* => *isIncorporatedOn* => *SensorUnit* • *SensorUnit is-a subclassOf AutomaticFireDetectionSystemComponent* • *AutomaticFireDetectionSystemComponent* => *isComponentOf* => *AutomaticFireDetectionSystem* • *AutomaticFireDetectionSystem* => *detects* => *Fire*



Questions	Axioms
How to transmit alarm to the occupants?	• *Sensor* => isIncorporatedOn => *SensorUnit* • *SensorUnit* => *triggersAlarm* => FireAlarm • *FireAlarm* => *warns* => *Occupant*

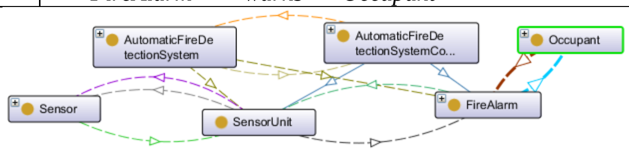


Table 3. Axioms obtained with SPARQL and related graphical representation.

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