An Ontology and a Reasoning Approach For Evacuation in Flood Disaster Response

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Abstract. Managing flood-related data to assist in the disaster management is a critical process of high importance during a flood disaster. These data are heterogeneous and can be provided from different data sources, and integrating them is a challenging task which allows to infer new information that helps in limiting the consequences of a flood. In this paper, we propose a novel approach that manages heterogeneous flood-related data based on semantic web techniques and helps in limiting the damage caused by floods. We first propose an ontology that is used to formally describe the flood-related data, and we build our knowledge graph through integrating heterogeneous data using the proposed ontology. Then, we propose a reasoning approach using SHACL rules to infer new information that helps in managing the flood disaster or in anticipating future events. The experimental evaluations of our proposed approach are conducted on a real case study in the frame of flood disaster management with the aim of generating evacuation priorities. The results show that it succeeds in managing heterogeneous flood-related data and generating evacuation priorities in a very short time.

Keywords: Flood disaster management ; Semantic web ; Flood ontology ; Reasoning ; SHACL rules

1. Introduction

Natural disasters, such as floods, are known to be dangerous and adverse events resulting from natural processes of the Earth. They could result in damage of properties, infrastructures and economy. In addition to the materialistic damage, they could most importantly lead to loss of lives, disruption of normal life of the population leading to food and water deficiency, disturbance of communication, displacement of victims, etc. From here comes the urgent need of disaster management processes in order to handle such situations of flood disasters. The disaster management process involves heterogeneous data collected from different sources, and they need to be integrated and used in different phases of the disaster management process. The disaster-related data are usually difficult to manage due to its large amount of diversity and heterogeneity of its nature. Extracting information and making accurate inferences from various data sources quickly is critical for natural disaster preparedness and response. Critical information about disasters needs to be provided in a structured and easily accessible way in a context-specific manner (Sermet and Demir, 2019). Therefore, the challenge lies in managing these data in an efficient way in order to help in the process of disaster management and decision making.

Heterogeneous data can be structured and formalized in a knowledge graph that relies on a shared vocabulary represented in an ontology. An ontology is defined as a formal, explicit specification of a shared conceptualization (Studer et al. 1998). It allows a structuring and a logical representation of knowledge, expressing the explicit and implicit relations between concepts. The ontology is used to describe data in a knowledge graph which expresses the domain entities related to the considered data and their relations. This enables knowledge to be machine-processable for better information retrieval and analysis. Ontology-driven systems have gained popularity as they enable semantic interoperability, flexibility, and reasoning support (Schulz and Martínez-Costa, 2013), and they allow to overcome heterogeneity and to have a consistent shared understanding of the meaning of information (Elmhadhbi et al. 2019). Ontologies have been used in the domain of flood disaster management in order to integrate and share flood-related data as well as to infer new information from these data thus helping in the disaster management process.

The disaster management has been described in the literature as a life-cycle, and it is categorized into four main phases: mitigation, preparedness, response and recovery (Franke, 2011). This work is conducted in the frame of "ANR inondations" e-flooding project[1].

[1] https://anr.fr/Projet-ANR-17-CE39-0011

This project focuses on the mitigation and response phases where it aims at integrating several disciplinary expertises to prevent flash floods and to experiment the effects of decision making on two timescales: short-term and long-term. The short-term timescale aims at optimizing the disaster management process during the disaster, while the long-term timescale aims at improving the territories' resilience for risk prevention from five years to ten years after the disaster.

This paper aims at proposing a solution for limiting the damage caused by floods. The main contributions of this work consist of relying on semantic web techniques to manage heterogeneous flood-related data through proposing a flood ontology that formally describes the heterogeneous data. Using this ontology and reasoning rules, we then infer new information that can assist in the flood disaster management process or in anticipation concerning floods. A main advantage of our approach is that it can be reactive as well as predictive. It is reactive as it manages real data of an occurring flood, and the proposed reasoning rules can be activated or deactivated in the appropriate phases of the flood. In addition, the reasoning rules can also be executed on predictive data for the purpose of anticipating future events or information. For example, using our approach, we can generate evacuation priorities of the places containing victims to be evacuated, we can infer the number and types of vehicles needed for evacuation in different zones, or we can improve the resilience of a territory through identifying vulnerable stakes. In our work, we evaluate our approach using a case study which falls in the short-term timescale of flood management where it aims at helping in the process of evacuation of flood victims during a flood, as a disaster response, through generating evacuation priorities for the places impacted by a flood and containing victims. This paper is organized as follows. Section 2 presents the literature review about ontologies proposed in the domain of natural disasters and floods and their different uses. Section 3 presents our approach and our data and details our proposed ontology. Section 4 discusses the process of building our knowledge graph. The reasoning approach using rules is detailed in section 5, and the approach is evaluated in section 6. Finally, the conclusion and the future work are presented in section 7.

2. Literature Review

Ontologies have been widely proposed in the literature in various domains, including domains of natural disasters and floods. From the review of the literature in these domains, we notice that ontologies are proposed for different uses, integration of heterogeneous data provided from various sources, information management and sharing among different actors and reasoning to infer new information. We first discuss the different uses and the proposed ontologies; then, we analyze these works.

One use of the ontologies is the integration of disaster-related data provided from various sources. Several approaches proposed ontologies for integrating homogeneous or heterogeneous data from one or more data sources. Scheuer et al. 2013 propose an ontology-based risk assessment workflow that performs flood assessment based on a computational model and focuses on integrating and operationalizing "local knowledge" in the process of flood risk management, where they define the local knowledge as the knowledge comprising the preferences of stakeholders and decision makers. These preferences are expressed by describing the data through their proposed ontology. Their concepts include "hazard" that is reused from Monitor ontology (Kollarits et al. 2009) in order to define an event and "event" that is reused from SWEET ontolgy (Raskin and Pan, 2005) in order to define a flood. A "flood" is described by a "recurrence interval" and an "intensity", and it describes an "inundation" and a "hydrospherePhenomena" that are reused from SWEET ontology. In addition, they define "population" that encompasses the most vulnerable age classes including children and elderly, "material infrastructure" as a subclass of "built environment" already defined in Monitor ontology. They define an "element at risk", for example a residential building and they reuse the "vulnerability" of an element at risk from MONITOR ontology. They also reuse flood's "duration", "area" and "inundation depth" from SWEET ontology. The concepts defined in this proposed ontology are important for flood disaster management and evacuation including "population", "elements at risk" and "infrastructure". However, infrastructures in their ontology are managed in a separated manner and can't be regrouped to describe an aggregation of the infrastructure, while this concept is important especially when no precise information about a specific infrastructure exists. Wang et al. 2018 propose a hydrological sensor web ontology to integrate heterogeneous data provided from different sensors effectively during periods of natural disasters. Their ontology is based on three existing ontologies: Sensor, Observation, Sample, and Actuator (SOSA)[2], Time[3] and GEOSPARQL[4]. They use the concepts "sensor" and "observation" from SOSA ontology.

They extend it using Time ontology for integrating temporal concepts including "Temporal Entity" class and "Instant" and "Interval" sub-classes. Then, they extend it using GEOSPARQL ontology to add geospatial dimensions using concepts including "covers", "crosses", "meets" and "within". This approach is interesting when the data mainly concerns sensors; however, the objective of our work is to manage data that are not restricted to sensors but are heterogeneous and are provided from various sources.

Another main use of the ontologies in the domain of natural disasters is information management and sharing among different actors involved in the disaster management process. Disaster-related data are usually of big amounts and are provided by different actors. In this context, ontologies are proposed with the aim of sharing data among different involved actors and solve the problem of interoperability of communication among them. Khantong et al.2020 propose a flood evacuation ontology for the purpose of improving the efficiency and effectiveness of information management in a disaster response and solving the problem of information sharing among different responders, organizers or processes handled by different systems in organizations. In their proposed ontology, they have concepts describing both static and dynamic data. They use concepts from the unified foundational ontology (UFO) (Guizzardi, 2005) to describe static data; their static concepts include "organization", "area", "flood event", "flood evacuation" and "victim". They use concepts from the Design and Engineering Methodology for Organizations (DEMO) ontology (Dietz, 2010; Sprengel et al. 2000) to describe dynamic data; their concepts describe production and coordination acts. It is an interesting approach as it allows managing static and dynamic data; however, the concepts describing the flood, victims and evacuation centers do not describe detailed data about them, and no detailed concepts are defined to describe the infrastructure that is important for flood evacuation. Yahya and Ramli, 2020 discuss that flood-related data may be inaccurate or unavailable if not regularly upgraded. Therefore, they propose an ontology for formally describing data provided from different actors involved in the disaster management process. They construct an ontology for each actor, and they aim at integrating all the ontologies in a global ontology. In their work, they propose only one ontology concerning evacuation centers for managing the flood victims. They reuse existing ontologies including SEMA4A for emergency notification systems accessibility (Malizia et al. 2010), a fire emergency management ontology (Nunavath et al. 2016), an ontology for accessible evacuation routes for emergencies (Onorati et al. 2014) and earthquake evacuation ontology (Iwanaga et al. 2011). Their proposed concepts describe general data about victims such as age, gender, address and number of victims as well as data about evacuation centers such as location and capacity, while there are no concepts describing infrastructure, population in infrastructures or elements at risk, while these concepts are important for an efficient evacuation process.

A third use of the ontologies in the domain of natural disasters is for conducting reasoning on knowledge graphs to infer new information related to the flood. Wang et al. 2018 propose an ontology (previously described in this section) and construct their knowledge graph and query it using SPARQL query language[5]. They then execute SWRL rules on the knowledge graph to infer flood phases from the precipitation of water level and observation data. Kurte, Durbha, King, Younan, and Potnis 2017 aim at understanding the dynamic spatio-temporal behavior of a flood disaster. For this aim, they construct an ontology that captures dynamically evolving phenomena. The ontology uses "SIIM" (Kurte et al. 2016) and "Time" ontologies to describe geospatial and time concepts. Geospatial concepts include "geospatial region" and time concepts include "time interval" and "time slice". As a reasoning approach, they execute SWRL rules to retrieve image regions based on their temporal interval relations. The rules that are used in the literature for the reasoning have limitations including identification, execution order and activation. Therefore, we propose a reasoning approach that handles these limitations.

2 https://www.w3.org/TR/vocab-ssn

3 https://www.w3.org/TR/owl-time

4 https://opengeospatial.github.io/ogc-geosparql/geosparql11/index.html

5 https://www.w3.org/TR/rdf-sparql-query

The ontologies proposed in the literature provide concepts describing floods, victims, infrastructures, population, elements at risk and vulnerability. These are important concepts to be considered for flood evacuation; however, certain concepts are not detailed enough. For example, aggregating different categories of infrastructures to solve the problem of unavailable data is not considered in the literature. In addition, there isn't an ontology that manages static and dynamic data with considering spatio-temporal dimensions. In our proposed ontology, we aim at handling these limitations through our defined concepts and relations.

3. Approach presentation

The general purpose of our proposed approach is to manage heterogeneous flood-related data provided from different sources to help in the flood disaster response. The main interest is to assist in the decision making process of evacuation of victims of a flood by generating evacuation priorities to the places impacted by the flood. Figure 1 displays the different steps of our proposed approach. We propose a flood ontology that formally defines the vocabulary that are used for describing these data through defining concepts and relations among concepts. Then, we build a knowledge graph using the proposed ontology to integrate all heterogeneous data. After that, we reason over this knowledge graph to infer new information. This information represents evacuation priorities to each place of the study area impacted by the flood.

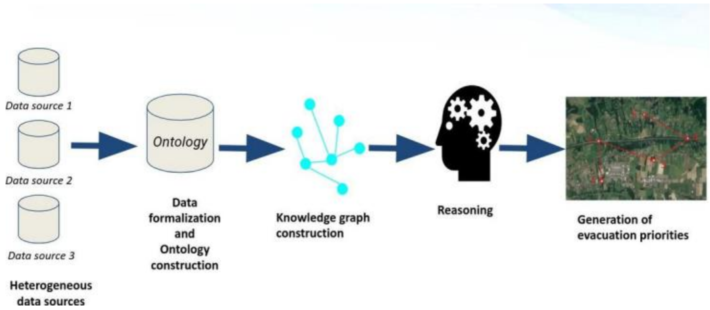

Fig. 1. Our proposed approach for generating evacuation priorities

3.1 Ontology design methodology

For the construction of our proposed flood ontology, we adopt a cyclic workflow that is proposed in NeOn design methodology (Suárez-Figueroa et al. 2015). This workflow is composed of four distinct phases: specification, conceptualization, formalization and implementation and finally evaluation. The specification consists of determining the domain, scope and purpose of the ontology as well as the use cases allowing to determine the role of the ontology. In the conceptualization phase, a glossary is built by adding definitions or common descriptions to each term. The terms are structured and then definitions of the basic concepts that are considered the most important and that align with the scope of the ontology are added. The relations are then modeled among concepts, which is the purpose of the formalization and implementation phase, during which a formal representation that is interpretable and computable by a machine is made. Finally, the developed ontology is tested against determined use cases in the evaluation phase. The results of these different steps are presented in the following sections. The ontology is written in OWL (Ontology Web Language)[6], and it is developed using Protégé[7], an ontology editor developed in Java that allows to load and save ontologies in most formal ontology representation languages, such as OWL.

6 https://www.w3.org/OWL/

7 https://protege.stanford.edu

3.2 Description of our data

The data available in our study concern the flood of Pyrénées that occurred in June 2013 in Bagnères-de-Luchon, south-western France. It was a torrential flood particularly destructive and very dangerous for the population. The consequences of this flood include destructed houses, cut roads, flooded campsites and damaged farms. 240 people were evacuated from the areas impacted by this flood. Figure 2 shows our study area.

The data of our study area are provided from various data sources. These sources include institutional databases such as BD TOPO[8] and GeoSirene[9]. They provide data about hazards, vulnerability, damage and resilience. Certain data sources provide data about geographical locations of roads, buildings, companies and establishments in France that are represented in QGIS[10], a cross- platform desktop geographic information system application that supports viewing, editing, and analysis of geospatial data. Other data are provided from various other data sources. These sources include data sensors providing data about water levels and flows, a hydrological model computing flood generation, a hydraulic model for flood propagation as well as other sources providing data about resilience corresponding to some actions taken from the past, socio-economic data and population data. Figure 3 shows the data used to feed our knowledge graph.

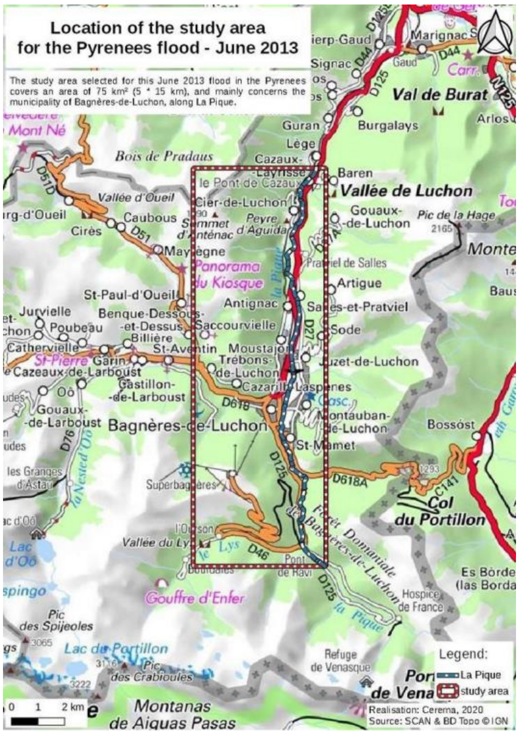

Fig. 2. Study area for Pyrénées flood in Bagnères-de-Luchon, France

8 https://www.data.gouv.fr/en/datasets/bd-topo-r/
9 https://data.laregion.fr/explore/dataset/base-sirene-v3-ss/
10 https://qgis.org/en/site

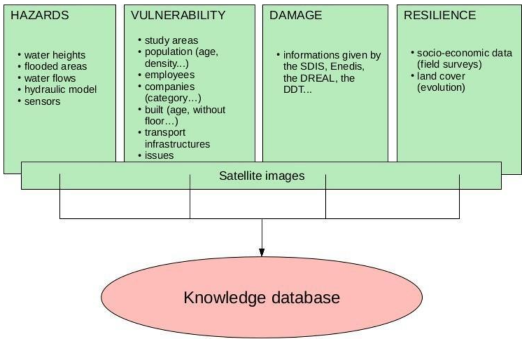

Fig.3. Data used to feed knowledge graph

Part of the data are accessible using QGIS. These data are categorized in two different formats representing two types of QGIS layers: raster layers consisting of masters of pixels and vector layers representing two-dimensional tables of various attributes. In the available data, there are data representing water levels that are the result of a hydraulic model, danger index of the flood, stakes, vulnerability and risk indexes. The calculation of these indexes are determined by the domain experts. These data can be divided into two categories: static and dynamic. The static data are those that don't change during the flood including number of floors, areas and geographic locations, while the dynamic data are those evolving throughout the flood including water level and population.

3.1 Ontology content

As our main objective is to manage flood-related data in order to generate evacuation priorities, we propose an ontology that contains the needed concepts, properties and relations that allow attaining this objective. The ontology representation is made through a hierarchy of classes (concepts) describing heterogeneous data involved in the flood phases, data properties which provide information about the characteristics of the classes and the relations which represent the object properties allowing to link the classes together.

We describe infrastructures in our proposed ontology as follows. A material infrastructure class is decomposed in several sub-classes: facility, habitat, working place and other kinds of infrastructure. A facility represents a commercial area, educational facilities such as schools, healthcare facilities such as hospitals and retirement homes as well as transport facilities such as railroad, railway station, road and tunnel. A habitat represents apartments, camping dwellings, hotels and houses. A working place represents administration sites, factories and offices. Another sub-class is also defined to describe any kind of infrastructure that is not one of the above. We detail all these different types of infrastructure in our ontology because it is important for the further reasoning process concerning the evacuation.

In addition to the material infrastructure class that allows managing each infrastructure on its own, we introduce a novel class, named infrastructure aggregation, which allows managing the different infrastructures in an aggregated manner by regrouping them in districts, buildings and floors. For example, we can describe that the district has buildings, the building has floors, and the floor has apartments by linking each two of them using the relation "has part". Thus, we can define for a district all the infrastructure that it contains. This relation is useful especially for the further step that consists of assigning evacuation priorities using rules because in the case when we only have general information about a district, we can assign a priority for all the infrastructures in this district.

The population class describes the population (number of persons) in all the infrastructures. It is divided into 2 sub-classes: fragile and non-fragile persons, and it is reused from the ontology proposed by Scheuer et al. 2013 with some additional details. The fragile population class is a defined class expressing that its instances are persons older that 65 years, children, and persons with disabilities, reduced mobility or illnesses. It represents the category of persons that need to have a high priority of evacuation when a flood occurs. Non-fragile population thus represents all the persons that are not fragile. The relation "is in" defines that a type of population is inside an infrastructure (or infrastructure aggregation). We define a demand point as a point that can be impacted by the flood and needs to be evacuated. It is similar to the class "element at risk" defined by Scheuer et al.2013 as a demand point can represent an element at risk. We thus define in our ontology a class named demand point that is a union of the two classes: infrastructure and infrastructure aggregation. Each infrastructure or infrastructure aggregation is considered as a demand point and thus a priority should be assigned to it in a further step. The demand point class has 4 sub-classes describing different priorities of evacuation: evacuate immediately, evacuate in 6 hours, evacuate in 12 hours and no evacuation. These 4 priorities are used in a further step for assigning one of them to each demand point based on rules defined according to the domain experts knowledge.

The data properties are divided into two categories, static and dynamic properties that add characteristics to the instances of demand point and population classes. The static properties concern the instances of the demand point class. They are usually determined before the crisis and allow to specify the structure of each demand point and its resilience to flooding. These properties represent building's vulnerability index, construction year, area and whether it has a basement or not They also include the floor and the number of floors when a building contains several floors as well as a property describing whether the building consists of only one floor. In addition, they include an important property that describes the geographic coordinates of a demand point, represented as “x” and “y” coordinates. The dynamic properties that evolve throughout the crisis concern the class “demand point” and represent the following characteristics: number of population, danger index, submersion height, flood duration, flood phases, number of fragile persons, whether the demand point is inhabited or not, number of population as well as approximate number of population when the exact number can't be determined.

Our proposed ontology consists of 41 classes, 6 object properties and 23 data properties. An overview of the ontology is displayed in Protégé editor is presented in figure 4. The ontology is available online via the following URL: https://www.irit.fr/recherches/MELODI/ontologies/i- Nondations.owl

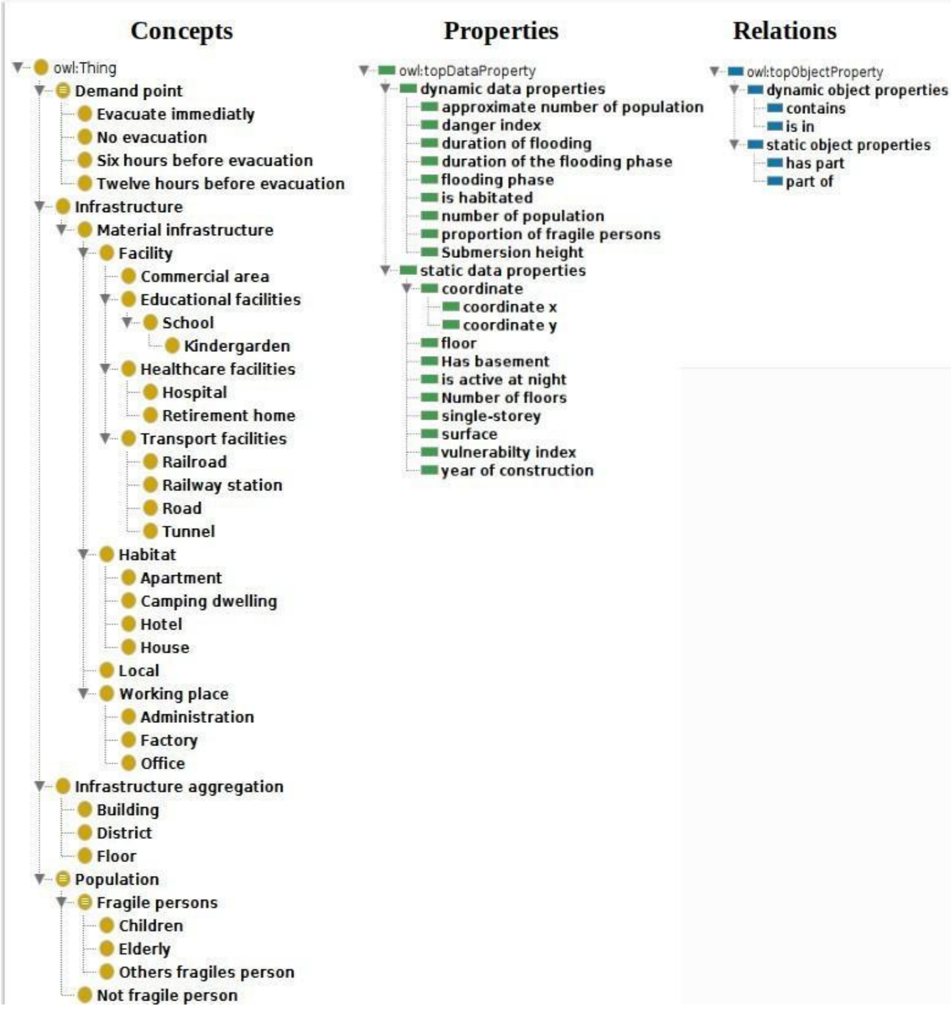

Fig. 4. Representation of our proposed ontology in Protégé

4. Knowledge graph construction

Building our knowledge graph represents integrating all the heterogeneous data using the ontology. In other words, it concerns integrating data through defining instances of the concepts and the properties of the ontology represented in the form of RDF triples. We recall that the heterogeneous data represent static and dynamic data. Therefore, we integrate static and then dynamic data to form our complete knowledge graph. Figure 5 presents the different steps of knowledge graph construction. First, we integrate static data by performing a joining process of these data from the different raster and vector layers containing them in QGIS as well as other sources such as BD TOPO. We then transform these integrated static data into static RDF triples that are added to the base ontology. In a further step, we integrate dynamic data by making a joining process for all the raster and vector layers containing these data in QGIS as well as other sources including a hydraulic model providing data about water level and flow speed and sources containing sensor and population data. We then transform the integrated dynamic data into dynamic RDF triples that are added to the base ontology and the rdf static triples, thus forming our knowledge graph that contains static and dynamic flood-related data. These processes are performed using “PyQGIS” API, the Python environment inside QGIS as well as other processes of data extraction adapted to each considered source, and “rdflib” python library is used to generate RDF data.

The last step consists of storing all the RDF triples constituting our knowledge graph in a triplestore, also named RDF store, that is a purpose-built database for the storage and retrieval of triples through semantic queries. We have chosen Virtuoso triplestore for storing the triples as it proves its efficiency in storing a big number of triples in a short time. For example, the results of a benchmark show that Virtuoso is able to load 1 billion RDF triples in 27 minutes while other triplestores take hours to load them such as BigData, BigOwlim and TDB[11].

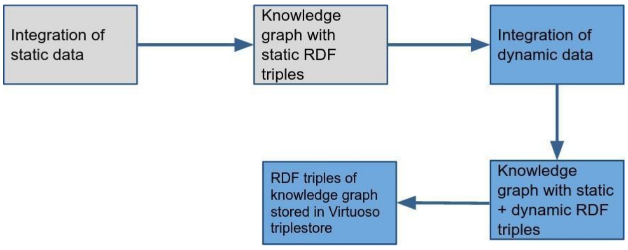

Fig. 5. Knowledge graph construction

5. Semantic reasoning: generation of evacuation priorities

We recall that our purpose is to assist in the decision making process of evacuation of victims as a flood disaster response. After building our ontology that formally describes the flood-related data and the knowledge graph that integrates the data using the ontology, the next step is to conduct a reasoning process that allows inferring new information in the form of evacuation priorities assigned to each demand point. Rules are used in the literature for inferring new information; however, they have certain limitations. They do not have identifiers, and thus a rule can not be well identified. It is also not possible to determine an execution order using these kinds of rules in case there is more than one rule. In addition, as long as the rules exist, they are automatically activated and can not be deactivated upon need. In our work, we use a more recent kind of rules, named SHACL rules[12] that are used for the same purposes and overcome these limitations; in addition, they haven't been used in the domain of flood disaster management yet.

SHACL (Shapes Constraint Language)[13] is a World Wide Web Consortium (W3C) standard language that defines an RDF vocabulary to describe shapes, that are collections of constraints that apply to a set of nodes. One focus area of SHACL is data validation; however, the same principles of describing data patterns in shapes can also be exploited for other purposes. One purpose is using SHACL rules to derive inferred RDF triples from existing asserted triples using SHACL rules engine. A SHACL rules engine is a computer procedure that takes as input a data graph and a shapes graph and is capable of adding triples to the data graph. A SHACL rule is identified through a unique Internationalized Resource Identifier (IRI) just like any resource in contrary to other kinds of rules. In addition, it can be activated or deactivated based upon its usage purpose where a deactivated rule is ignored by the rules engine and is thus not executed. An order of execution can also be determined for SHACL rules when more than one rule is executed. SHACL rules allow not only to infer new information but also to enrich the knowledge graph with this inferred information. There are different types of SHACL rules including SPARQL rules that allow writing rules in SPARQL notation. We use SPARQL rules in our reasoning process for generating evacuation priorities. We define a rule for each evacuation priority as follows. First, we define the node shapes representing the classes that describe the priorities and the property shapes representing the properties used to define the evacuation priorities. After that, we define our rules. Each rule contains the conditions that need to be satisfied for each property (detailed later).

The rules are then executed on the knowledge graph to infer new triples. Each inferred triple consists of a demand point with an evacuation priority assigned to it according to its properties. The knowledge graph is then enriched by adding these inferred triples to it in the triplestore.

11 http://wbsg.informatik.uni-mannheim.de/bizer/berlinsparqlbenchmark/results/V7/#exploreVirtuoso
12 https://www.w3.org/TR/shacl-af
13 https://www.w3.org/TR/shacl

Various priorities to be assigned to the demand points are determined. First, a set of properties that define each evacuation priority is determined; then, the conditions that need to be satisfied for each priority are set. The properties determining the evacuation priorities represent certain static and dynamic data. The evacuation priorities and the conditions defining them are determined by domain experts, that are the firefighters concerned in the evacuation process, as well as other factors including the study area and the available data. Although a specific set of properties define the evacuation priorities in this work, it is dynamic and can be changed as our approach is generic, and it is not restricted to a specific study area or data nature.

6. Approach Evaluation

In this section, we discuss the evaluation of our proposed approach using the available data of our study area starting from building our proposed ontology to constructing the knowledge graph until generating the priorities using SHACL rules and enriching the knowledge graph with the inferred triples.

6.1 Our Knowledge graph construction

As discussed in section 3, static data are first integrated and transformed into RDF triples. The processes of joining the static data and transforming them to RDF triples are executed in 24 seconds. 245,644 static triples are generated and added to the triples representing the ontology. After that, the dynamic data are integrated and transformed to RDF triples in 174 seconds. 225,766 dynamic triples are generated and added to those of the ontology and the static data thus forming our knowledge graph.

After the knowledge graph construction, our next step is to conduct a reasoning process using SHACL rules to infer new information in the form of evacuation priorities. First, we determine the different types of evacuation priorities with the used properties and their conditions. Then, for each kind of evacuation priority, we define a SHACL rule that allows, when executed, to assign for each demand point an evacuation priority based on its properties.

6.2 Determining evacuation priorities

The domain experts involved in our project have determined four types of evacuation priorities: evacuate immediately, evacuate in 6 hours, evacuate in 12 hours and no evacuation. The definition of these evacuation priorities relies on several properties representing static and dynamic data. The properties representing static data are: number of floors and vulnerability index, while the properties representing dynamic data are: submersion height, danger index, duration of flood and number of population in a demand point. The vulnerability index is calculated by joining different topographic and social data such as population density, building quality and socio-economic conditions. The danger index is calculated by joining the speed of water flow and the level of water obtained from a hydraulic model.

```
Evacuate in 12h if:
Demand_point contains Population
0 < danger_index < 50
duration_of_flood > =12
number_of_floors >= 1
0.0 < submersion_height <= 1.0
vulnerability_index < 50.0
is_habitated is True
```

Each type of evacuation priority is defined through setting conditions on the considered properties, and each demand point that satisfies the conditions of a certain type of evacuation priority is then assigned this priority. For example, if a demand point represents an infrastructure of high priority, such as a school or a hospital, and if it contains population, then it is determined to be evacuated immediately as is thus assigned the priority “evacuate immediately”. On the other hand, if a demand point doesn’t contain population or has a danger index or a submersion height <= 0, then it is considered that there is no need to evacuate it and is thus assigned the priority “no evacuation”. An example of the priority “evacuate in 12 hours" with its properties and conditions is presented as follows. Similarly, the three other evacuation priorities are defined each having its own conditions.

6.3 SHACL rules for generating evacuation priorities

For each type of evacuation priority, we implement a SHACL rule that defines its conditions as follows. We start by defining the properties that are used in the rules. Then, we define 4 rules where each rule represents a type of evacuation priority and contains the conditions set for each property. An example of a rule defining the type of evacuation "evacuate in 12 hours" is as follows.

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix sh: <http://www.w3.org/ns/shacl#>.
@prefix ns1: <https://www.irit.fr/recherches/MELODI/ontologies/i-Nondations.owl#>.
ns1:12h_before_evacuationRulesShape
rdf:type sh:NodeShape ;
sh:targetClass ns1:Demand_point ;
sh:rule [
rdf:type sh:SPARQLRule ;
sh:prefixes ns1: ;
sh:construct """
PREFIX ns1: <https://www.irit.fr/recherches/MELODI/ontologies/i-Nondations.owl#>
CONSTRUCT
{?this ns1:priority ?priority.}
WHERE
{  ?this ns1:danger_index ?danger_index.
   ?this ns1:duration_of_flooding ?duration_of_flooding.
   ?this ns1:number_of_floors ?number_of_floors.
   ?this ns1:submersion_height ?submersion_height.
   ?this ns1:vulnerability_index ?vulnerability_index.
   ?this ns1:is_habitated ?is_habitated.
   FILTER
   (?danger_index > 0 && ?danger_index < 50
   && ?duration_of_flooding >= 12
   && ?number_of_floors >=1
   && ?submersion_height > 0.0 && ?submersion_height <= 1.0
   && ?vulnerability_index < 50.0
   && ?is_habitated = true ) .
   BIND ("12h_before_evacuation"  AS ?priority).
   }
    """ ;
    sh:condition ns1:12h_before_evacuation ;
];
```

The rules are executed using TopBraid SHACL API[14], an open source implementation of the W3C SHACL based on Apache Jena[15]. We execute our rules on the knowledge graph and infer triples representing evacuation priorities assigned to every demand point in the knowledge graph according to their properties. The execution order of the rules is not important in our case as the interest is assigning priorities to every demand point in our study area.

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[13] https://github.com/TopQuadrant/shacl
[14] https://jena.apache.org/

There are 15,078 demand points in our study area; therefore, 15,078 new triples are generated with corresponding evacuation priorities for demand points. Table 1 shows the number of triples generated after each process in our approach.

Table 1. Number of triples generated after each process in our approach

Process	Knowledge graph with static data	Knowledge graph with static and dynamic data	Complete knowledge graph with priorities
Number of triples	246,828	472,594	487,672

The SHACL rules were executed in 9.96 seconds which represents the time of assigning priorities to all demand points. Figure 6 displays the execution time of various processes in our proposed approach.

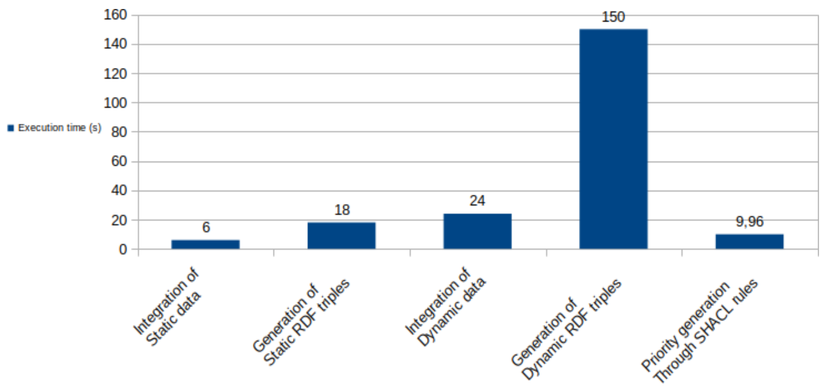

Fig. 6. Execution times of various processes

An example of a newly inferred triple is as follows.

```
<https://www.irit.fr/recherches/MELODI/ontologies/i-Nondations.owl#DP_12345>
 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
  <https://www.irit.fr/recherches/MELODI/ontologies/i-Nondations.owl#evacuate_
  in_12h>
```

This triple represents an evacuation priority “evacuate-in-12h” assigned to the demand point “DP_12345”. The properties of this demand point are as follows:

```
"DP_12345":
danger_index = 25
duration_of_flood = 24
number_of_floors = 3
submersion_height = 1.0
vulnerability_index =  7.02
is_habitated = "true"
```

As we can see, the properties of this demand point satisfy the conditions of the evacuation priority “evacuate in 12h”; therefore, this type of priority is assigned to it.

These results show that our proposed approach succeeds in attaining its objective. The construction of the knowledge graph including all the static and dynamic data of our study area only takes 198 seconds, and the reasoning process generating evacuation priorities for each demand point in our study area only takes 9.96 seconds. Responding to the flood disaster in a short time is important especially concerning evacuating victims and saving lives. Therefore, our approach succeeds in assisting in the flood disaster response phase through generating evacuation priorities to demand points in a short time and thus helping the firefighters in the decision making process concerning the evacuation.

6.4 Visualization of evacuation priorities in QGIS

As previously discussed, the reasoning process allows inferring new information in the form of evacuation priorities to demand points in our study area. The knowledge graph is then enriched by adding the newly inferred triples to it. Figure 7 shows the data visualization represented in QGIS after adding the evacuation priorities. As shown in the figure, the evacuation priorities of the demand points are displayed in different colors as follows: “Evacuate-immediately” is displayed in red, “Evacuate-in- 6h” is displayed in blue, “Evacuate-in-12h” is displayed in yellow and “No-evacuation” is displayed in green. In our study area, the number of demand points assigned an evacuation priority “Evacuation-in- 6h” is very small with respect to the others that are assigned other evacuation priorities (31 out of 15,078 demand points). Therefore, in the figure, we only choose to display the three other evacuation priorities. The gray and black zones represent water levels; they are thus the zones where we have demand points represented in red and need to be evacuated immediately.

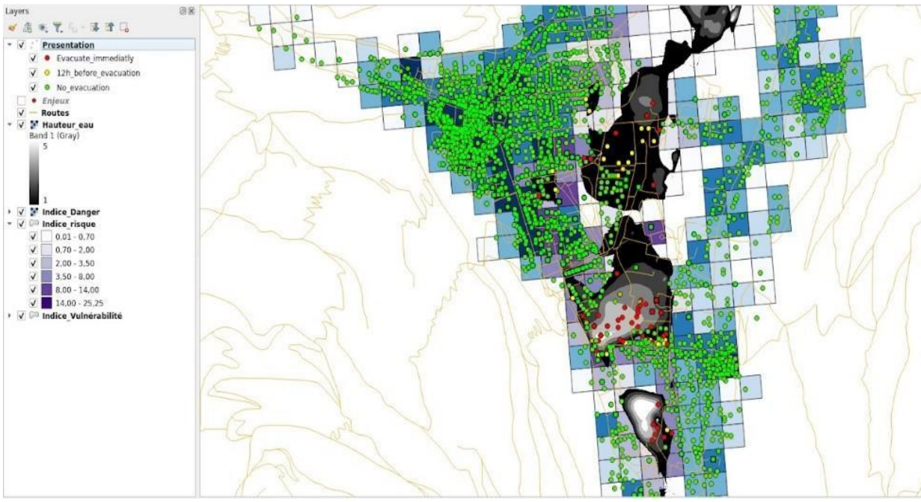

Fig.7. Visualization of data layers in QGIS with evacuation priorities

7 Conclusion

In this paper, we have proposed a novel approach of managing heterogeneous flood-related to assist in the flood disaster management process When a flood occurs, there is an urgent need for a flood disaster response concerning victims’ evacuation to save their lives in an efficient manner. Therefore, we have proposed an approach that manages flood-related data and generates evacuation priorities of flood victims to help the firefighters in the decision making process of evacuation. We have thus proposed an ontology that formally describes heterogeneous flood-related data; then we have built our knowledge graph through integrating static and dynamic data available in our study area. A reasoning process have then been conducted on the knowledge graph to assign evacuation priorities for all the demand points. The reasoning process is performed using SHACL rules that are more recent and advantageous over other kinds of rules already used in the literature. The experimental results prove that our approach succeeds in generating evacuation priorities for all demand points of the study area in a short time. As a future, work, we aim at proposing an interface that helps domain experts to elaborate the reasoning rules according to available data during the different flood stages, to activate or deactivate them and to provide an execution order to the rules upon need. Furthermore, this interface would allow executing rules on past data to improve the flood disaster management, on real-time data to manage a current flood disaster and on predictive data to anticipate future events or actions.

Acknowledgments

This work has been funded by the ANR[16] in the context of the project "i-Nondations" (e-Flooding), ANR-17- CE39-0011.

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