# Supporting Global Knowledge Concerning Risk Domain: Ontologies Put into Practice

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**Abstract.** Developing strategies and solutions to cope with the increasing risks that populations constantly face has become essential to encourage effective preventive planning and prompt responses. In this regard, and from a more theoretical perspective, the relevance of developing a formal conceptualization of the world by linking concepts through logical rules to allow knowledge sharing is recognized as the primary purpose by the Authors. Users working in the same Risk domain, intended as a function of Hazard, Vulnerability, Exposure, and Adaptation (as a reducing factor), require a system of explicit representations that can reduce the conceptual and terminological confusion to have a shared interpretation. Therefore, ontologies are employed to overcome such issues. Ontologies can improve semantic interoperability by isolating the core concepts' domain, defining relations among them, and providing hierarchically structured descriptions of the most important concepts and their properties. Thus, an ontology about the Risk domain has been built using the Protégé editor through some steps: identifying the main concepts related to the domain, organizing the concepts through a structured hierarchy that implements the IS_A relation, and finally specifying further possible relations existing among the inserted terms.

**Keywords:** Ontology design · disaster risk reduction – DRR · multi-risk approach

## 1 Introduction

Human existence deals with the exposure to multiple hazards. Understanding the hazards and their associated risks may help prevent or reduce adverse consequences. Considering that we live in a multi-risk environment with endless natural and anthropic hazards, many of which cannot be controlled and occur at any time, planning to reduce risk becomes more challenging [1].

A natural phenomenon (such as an earthquake, flood, or landslide) does not represent a disaster alone; nevertheless, it can turn into a disaster whenever it negatively impacts

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vulnerable communities, exposed and/or unprepared for the event. The interaction with the social, political, and economic context makes a natural phenomenon hazardous and produces risks [2]. Indeed, it was recognized the existing link among the concepts of 'risk', 'hazard', and 'society' [3].

Therefore, in a precise period, the complex interaction of dynamic processes that generate hazardous situations and conditions for human life and material goods define the concept of risk [4].

In the scientific literature, it is possible to find a considerable number of elements whose relations with 'risk' are often unclear: they assume different meanings in relation to the context (social, ecological, engineering, and so on). Starting from Blaikie [5], risk is considered a product of natural hazard (shaped by the magnitude and frequency of a physical event) and human vulnerability (result of the interaction of physical and human elements). Moreover, vulnerability can be defined as the interaction between exposure (directly dependent on geographical location, built and natural environment characteristics), resilience (the ability of each element to overcome or adapt to the stressful event), and resistance (the ability of a single individual or group of people to resist the impact from a physical, economic, psychological, and social point of view).

The complex and multidimensional concepts of risk, resilience, and territorial vulnerability can be explained as expressions of the territory as a complex system. During a hazardous event that generates interruption and uncertainty in its components, causing an increase in entropy, the territory can contrast an equal but opposite strength and resilience, increasing its levels of organization. Ecosystems, government, climate, society, and urban environment are all examples of complex and adaptive systems that, when perturbed by a natural or anthropogenic stressor, demonstrate a high capacity to adapt and return to a new state of equilibrium.

The interest and reference to the concept of multi-hazard risk (or multi-risk) was first made in the Agenda 21 Conference in Rio de Janeiro [6] and then in the Johannesburg Plan [7] in which a complete multi-hazard approach was proposed for disaster management and risk reduction.

Since then, many researchers focused on analyzing multiple risks deriving from different hazards and affecting different exposed elements. Hence, many scholars and international government bodies are trying to overcome a critical gap: the lack of precise definitions [8–11].

In particular, the multi-hazard concept is related to assessing different hazards, triggering cascade effects threatening the same exposed elements with or without temporal concurrence [12]. Multi-vulnerability considers different exposed elements with possible different vulnerabilities, changing according to different hazards and over time.

Consequently, the multi-risk concept refers to a complex variety of combinations of risks, various combinations of hazards (e.g., multi-natural hazards, multi-technological hazards, multi-natural and technological hazards combination, etc.) and various combinations of vulnerabilities (e.g., multi-population and buildings, multi-cultural and environmental, complex urban vulnerabilities, etc.) [13, 14]. The multi-risk approach aims at adopting a territorial perspective: a piece of territory is composed of elements at risk that are diversely vulnerable to the various sources of hazards that can affect that area.

Improving a shared understanding and mapping of the increasing risks of extreme and complex disasters is a fundamental pre-condition to understanding the required capability to manage disaster risks and to ensure robust preparedness planning and timely and efficient operational response. Indeed, the Sendai Framework divides its action into four main pillars (priorities) that underline different aims. Among the others, the relevance of supporting risk awareness in all its dimensions (exposure, vulnerability, and hazard) is highlighted, together with the fundamental recognition of the involved stakeholders and their roles in the processes.

Therefore, the paper discusses using ontologies for such purposes to improve the overall knowledge and understanding of the risk concept. An ontology is defined as "an explicit specification of a conceptualization" [15] of which it can explicitly formalize the semantics. Thus, they can work to increase the semantic operability and make the approach to risk definition more systematic.

On the one hand, starting from an abstraction process, the conceptualization step identifies the key concepts that are directly linked to the domain's terms. On the other hand, the specification action makes the meaning related to such concepts extremely clear, proving for them a formal definition that can be automatically decodable.

Therefore, an ontology dealing with the "risk" domain would develop a conceptual model describing the domain's entities and their relations, expressing the entities' attributes and values that such attributes could have. Additionally, it is possible to define rules concerning classes, attributes, and their relations. The success of similar operations is greatly supported by the development of specific automated technologies that can recognize and extract relations existing between concepts. Indeed, the authors choose Protégé as the main tool for building risk ontology. The Protégé editor is a "free, open-source ontology editor and framework for building intelligent systems" [16]. Stanford University developed it in the 1980s; to date, it is used by more than 250,000 people. The tool organizes the knowledge hierarchically by easily entering information that the user can always modify and navigate by interacting with the structured graph representing all the inserted concepts.

The main aim is to build a shared interpretation of the risk domain with its entities so that the various concepts are understandable to both heterogeneous stakeholders and systems, of immediate availability, and characterized by an intrinsic meaning that cannot be misunderstood.

After the introduction chapter, the paper proceeds by deepening the features of the multi-risk approach in connection with the use of ontologies as integrated tools. Therefore, the main features of ontologies linked to the Computer and Information Science field are explained; then, the methodology concerning how the risk ontology has been developed is described by putting in evidence the different designing phases that have employed the Protégé tool. The discussions and the description of future possibilities conclude the contribution.

## 2 Multi-risk Approach

From the International Decade for Natural Disaster Reduction (IDNDR) in the 1990s, the Hyogo Framework for Disaster Risk Reduction (HFA) 2005–2015 and the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030, science and technology (natural science, engineering to social science) have been recognized as driving forces in the development and implementation of major international disaster risk reduction (DRR) frameworks. Adopting a multi-risk approach is considered a priority in many documents and protocols, especially at the international level and several European research projects aiming at improving multi-risk assessment logic frameworks, methods, and instruments [17].

Despite this, the complex multi-sector dimension of DRR knowledge is quite evident and has not been adequately incorporated into the decision-making process [18]. In particular, among all the stakeholders involved: disaster managers, public administrators, scientists, scholars, NGOs, and experts coming from different disciplines (economics, business management, investment funds and insurance, urban planning, climatology, virology, and civil protection) with different roles and responsibilities in the risk analysis and management process, tend to prioritize different aspects of disasters and find difficulties to collaborate and coordinate during the DDR phases (prevention/mitigation, emergency, response, and restoration) [19].

Even if each typology of risk requires specific and customized efforts and analysis (risk scenario definition), many multidisciplinary principles can support the preventive phase of the DRR cycle: to implement the preparedness and the prevention, it is fundamental to define all the concepts involved (with a trans-disciplinary approach), to map interconnections and dependencies among systems, elements, and actors [20, 21].

Moreover, a multi-risk approach allows an improvement of urban planning and emergency planning with a shared database, information, and rules, significant cost reductions, improvements in the efficiency of risk mitigation and management measures, and better identification of solid actions to perform on the territory (Table 1.). In the case proposed by the authors, the approach also includes the application of risk ontologies. Indeed, integrating ontologies into the multi-risk analysis supports overcoming diverse challenges related to data heterogeneity, diversity of information systems, and complexity of risk interconnections. The latter can be clearly identified and capture the interactions between natural, technological, and socio-economic spheres, thus facilitating communication among stakeholders and enabling a common understanding of the risk domain.

**Table 1.** Benefits derived by the adoption of a multi-risk approach. Source: adapted from [22].

| Strategies/tools | Benefits |
|---|---|
| Risk assessment and land use planning | – Consideration of cascading effects and interactions between risks and inclusion in risk zoning and land use planning<br>– Comparison and ranking of different risk<br>– Identification of the highest risk in terms of potential impacts<br>– Standardization across risk fields |
| Emergencies management | – Development of multi-hazards and multi-risks scenarios to manage emergency situations in real-time<br>– Better preparedness due to knowledge of cascading effects |
| Emergency/Civil Protection Plans | – Identification of the phenomena expected in a territory, thus defining the possible risk scenarios<br>– Better identification of strategies to avoid or reduce possible damage after a hazardous event<br>– Enhancement of population awareness and preparedness facing emergency situations |
| Risk mitigation | – Better identification of action priorities<br>– Integrated practices<br>– Evidence on increased expected losses due to risk interactions<br>– Cost reductions and improvement in the efficiency of mitigation measures |
| Institutional capacities | – Improved cooperation and communication between agencies acting at different levels in different risk sectors |
| Public and private sector partnership | – Enhanced cooperation and communication between the public and private sectors<br>– Need for a new responsibility-sharing mechanism in the case of households exposed to multiple risks (insurance) |
| Risk Ontologies | – Automatic identification of potential risk scenarios<br>– Provision of a structured and interoperable conceptual framework<br>– Terminology standardization |

### 2.1 The Multi-risk Approach in the Italian Civil Protection Plan

In the Italian context, at the different territorial scales, considering the several tools linked to the study of risk factors in the planning discipline, emergency (or Civil Protection) planning represents a fundamental example of the multi-risk approach to risk analysis in all the DRR phases.

A Civil Protection Plan is constituted by a set of strategies, actions, and operational procedures for intervention to deal with any disaster occurring in a specific territory, but, at the same time, it is also the necessary tool to increase, in ordinary times, awareness of risk (as multi-risk), to organize the available resources and to guarantee the connection among the different administrations and governmental bodies based on a shared strategy. The Civil Protection Plan incorporates the forecast and prevention program. The emergency allows the authorities to prepare and coordinate rescue and response interventions to protect the population and the assets in a territory at risk.

Italian Law 225/1992 enhances the role of the Provinces (a territorial and governmental meso-level between Region and Municipality) in the planning sector, with particular reference to risk prevision and prevention. The Provincial Prediction and Prevention Programs represent the first and essential moment for analyzing and enhancing territory knowledge under the several risk hypotheses. They identify the areas at risk, evaluate the technical characteristics of the existing defense works, categorize the exposed elements, and describe the monitoring activity. They also outline the principal regulations directing to mitigate the effects of the expected hazard, identifying the probability of recurrence, the probable magnitude, the areal extension, the precursors, and the trigger events for each type of risk, and they are also an information tool for the population. These Programs represent the premise of the provincial and municipal emergency plans based on Legislative Decree 112/1998, L.R. 1/2000, and DLgs 1/2018.

At the provincial level, the Civil Protection Plan is a fundamental and necessary tool to face the complex world of civil protection emergencies. It refers to hazardous event scenarios that require the mobilization of the structures and components of the provincial and regional protection and planning system due to the extension and severity of the event scenarios themselves. It is mainly addressed to public administrations and experts. The Province, if a hazardous event occurs, coordinates its interventions with those implemented by the Prefecture:

- Must promptly activate its resources to deal with the emergency (with particular attention to infrastructure system, technological network, and facilities and services network);
- Organizes relief works at the provincial level and activates the urgent services;
- Follows the activation, coordination, and management of provincial volunteering to support the Civil Protection authorities in the territory (Mayor, Prefect).

## 3 Understanding the Significance of Ontology

The introductive chapter clearly highlights the intention to establish a common way of organizing knowledge regarding the risk domain, to make concepts understandable to an ampler set of stakeholders by establishing a formal and clear intrinsic meaning using ontologies.

The definition of ontology through the history of Western thought assumes different interpretations based on the field of study. Indeed, in one case, it refers to Philosophy, and Aristotle, who dealt with this subject in his Metaphysics, defined Ontology as the science of "being qua being". Therefore, Ontology examines the nature and structure of things regardless of their actual existence. Thus, for example, the Ontology describing unicorns or other fictitious entities is accepted: even if the latter lack evidence, their specific nature and structure can be explained through general categories and relations [23].

In the other case, ontology concerns Computer and Information Science and is identified as "a sort of informative object or computational artifact" [23]. Hence, the existential component is tangible, as Gruber [24] explained: "For AI systems, what 'exists' is that which can be represented."

The previously introduced definition by Gruber in 1993 is the most widely adopted and can be seen as a foundation for computer science tools that are based on ontologies. Indeed, conceptualization is a theoretical model that provides the fundamental concepts linked to a specific domain through an abstraction process; the meanings related to such concepts become unambiguous through a specification that gives them formal definitions that can be automatically decodable and shared between people and software agents [25].

In this regard, the term ontology has a broader meaning than the philosophical one. Indeed, an ontology reflects a formal description of knowledge in terms of concepts, relations between them, properties, and other elements in a specific domain [26]. The tool's conceptual value is well recognized. When applied to complex domains, it enables the capture, explicitation, specification, storage, maintenance, management, and representation of the implicit or explicit knowledge contained in it.

Then, in 1997, Borst specified additional requirements: the conceptualization should be placed at a wider level of shared participation and operated by a machine. He described ontology as a "formal specification of a shared conceptualization" [27]. The following year, Studer et al. [28] affirmed, "An ontology is a formal, explicit specification of a shared conceptualization."

In this way, they merged the previous definitions and elaborated a standard view among those who use this conceptualization and those who are the recipients of the advantages deriving from its adoption; indeed, Studer's meaning considers "a context instead of an individual vision" [23]. In the same year, another definition that emphasizes the role of logic theory as a tool in presenting ontology should be considered. In this sense, Guarino [29] explained, "An ontology is a set of logical axioms designed to account for the intended meaning of a vocabulary."

The number of ontologies available to the public has increased in recent years: some lack good quality, while others have a limited application range [30]. However, this context demonstrates how ontology implementation is no longer a resource for exclusively large projects with significant funding. Some factors contributed, such as the dissemination of the Semantic Web, the arrangement of techniques for engineering ontologies, increased literature about ontologies, access to a large variety of courses and tutorial possibilities, and much more [31]. During the last three decades, ontological studies have significantly developed, implementing theoretical models to more practical implementations directly connected to real-world and large-scale applications. As the

most positive outcome today, the ontological design aims at investing an ampler set of knowledge and different fields of science, such as urban planning, infrastructure, archeology, business, medicine, biology, etc. [32–34].

## 4 Applying the Ontology Tool to the Risk Domain

The logic scheme adopted to design the risk ontology considers the multi-risk vision. An elevated number of "hazards" and more "vulnerabilities" (objects and subjects are vulnerable in different ways according to the hazard to which they are subjected, and they respond to it in other ways, whether there is contemporaneity or concatenation of events, as well as the units of measure of such vulnerability change) insist on the same territory (being an exposed element) thus generating the study of multi-risk.

Indeed, such systematic vision is employed as a more truthful descriptor of the territory's complex reality to be analyzed and managed (from the point of view of risk reduction in the pre-and post-event, hence of the emergency phase).

Starting from the equation that defines the Risk as a function of Hazard, Vulnerability, Exposure, and Adaptation (as a reducing factor), the ontology has been built following a top-down approach. The latter proceeds by detecting the most general concepts (classes) in a domain, and subsequently, it integrates the structure by specializing it step by step. In this regard, Gandon [35] affirmed, "This approach is prone to the reuse of ontologies and inclusion of high-level philosophical considerations which can be very interesting for coherence maintenance."

Such a method was applied after the first phase, during which the main concepts related to the risk domain were detected by analyzing the existing literature; this action resulted in the drafting of a dedicated glossary that counted 130 terms. Those entities have been evaluated individually without finding common elements and reducing them to a comprehensive explanation. Indeed, a principle of adequatism has been followed, identified as the opposite of the reductionist philosophy, whose goal is to explain complex phenomena by reducing them to simpler and more essential elements.

The next stage consisted of the actual realization of the ontology so that the base knowledge structure could be highlighted once the domain's elements and their relations had been detected. The complex feature of reality, which clearly affects even the risk domain, implies multiple perspectives concerning ontological development [31]. Thus, a single ontology cannot pretend to describe an entire domain fully, and, therefore, the authors adopted a modular approach so that experts in the related scientific discipline can manage each ontology's sections. This is linked to the essential feature of ontologies that, like scientific theories, can be subjected to substantial changes and revisions to support their long-term utility and avoid placing attention on the local utility and the possible short-term effects. Ontologies keep undergoing maintenance, evaluation, update, correction, and adjustment operations to correctly consider further advantages in scientific and personal ontology knowledge.

### 4.1 The Protégé Tool

As previously mentioned, Protégé has been used to build ontology practically. The platform offers a suite of instruments that facilitate the construction of domain models

and knowledge-based applications with ontologies [36]. It basically provides a graphic and interactive editor for the organization of knowledge. The overall information can be quickly accessed by the users, who can edit it and interact with the ontology directly by browsing the graph and displaying it. The knowledge model used by Protégé offers the advantage of an architecture that guarantees an open and modular tool.

Protégé can interact through a variety of frameworks. In this case, the work has been developed using the desktop system (Protégé 5), which can support many advanced features to enable easy and fast construction and management; the latter is organized by labeled panels that differentiate the program's various functions from the visual point of view.

Using Protégé, the ontology is designed to describe the organizational information scheme. The latter comprises information grouped by classes and subclasses and expressed through a hierarchy. In this regard, the tool effectively implements an entity-relationship diagram, which incorporates relationships only of the type IS_A. Therefore, the main concepts collected in the glossary have been integrated into a taxonomic hierarchy where the nodes represent the classes, and the edges are connected through the IS_A relation. Figure 1 shows the entities' organization through the OWLViz plug-in, which displays only classes linked by this relation, organized by a node-link tree layout [37]. Due to the high number of entities that have been included in the ontology, and visualization quality issues, the picture is showing only a part of the overall design to emphasize how the software organizes the information in a very user-friendly and clear way.

Focusing for example on the hazard component, the most frequently identified disaster risks are addressed in three different categories: natural hazards, man-made hazards, and NaTech. Natural hazards (Fig. 2) are biological, climatological, geophysical, meteorological, extraterrestrial, and hydrological, by which events like epidemics, volcanic eruptions, earthquakes, landslides, and floods affect Earth's surface.

Some of these processes, such as volcanic eruptions and earthquakes, result from internal forces deep within Earth. Other processes are derived from external forces, such as the Sun energy, directly related to hazardous processes such as violent storms, flooding, and coastal erosion. Still, other external processes, such as landslides, result from gravity acting on hillslopes and mountains. The hazardous events have direct and indirect, positive or negative impacts. The term includes economic, human, environmental, and cultural heritage impacts and may include death, injuries, disease, and other adverse effects on human physical, psychological, and social well-being. Man-made and technological disasters, whether caused by natural or man-made hazards, can cause severe damage to individuals, communities, economies, supply chains, and the environment, impact livelihoods, and jeopardize long-term well-being. Man-made hazards (technological and human hazards) are defined as those "induced entirely or predominantly by human activities and choices" [38].

Indeed, the distinction between natural and man-made catastrophes is not always obvious. Most natural and man-made disasters present cross-border risks due to their geographical nature (earthquakes, fires, severe weather, floods, and space weather), as well as the volatility and scale of their impacts (pandemics, livestock epidemics,




**Fig. 1.** Partial Risk domain entities' organization through the OWLViz plug-in. Source: authors.




**Fig. 2.** Focus on Natural Hazard classification through the OWLViz plug-in. Source: authors.

nuclear/industrial accidents). Some events are wrongly assumed to be natural catastrophes: landslide at the Vajont Dam (Italy, 1963) as a result of the filling of the basin destabilizing the mountainside; forest fires in Indonesia (2015) as a combination of man and nature (the fires were started deliberately and the arid conditions expanded it); landslide in Shenzhen (China, 2015) where heavy rains had brought down an artificial dump of excavated soil and rubble.

Moreover, a technological accident caused by a natural hazard is known as NaTech, a term initially coined in 1994 by Showalter and Myers. Hazardous industries may be vulnerable to the impacts of natural hazards, so NaTech accidents are a frequent consequence of natural disasters. Under extreme climatic conditions, forest fires impact ecosystems' health and functions. They can cause extensive damage to life and property, as well as the disruption of transport systems and critical infrastructure (airports, power lines, etc.), businesses, and private assets. NaTech events can be potentially disastrous secondary damages caused by earthquakes, releasing hazardous materials and destroying vital transport and technical infrastructure, residential and industrial buildings, and facilities. Cascading effects of flood events may include the loss of vital infrastructure and damage to industrial facilities, causing the release of chemical or radioactive substances. The following Table 2 reports all the entities that have been integrated into the ontology, reporting definitions and examples.

**Table 2.** Disasters classification. Source: adapted from [38].

| | Type of hazard | Definition | Main examples |
|---|---|---|---|
| Natural Hazards | Biological hazard | A hazard caused by the exposure to living organisms and their toxic substances or vector-borne diseases that they may carry | Animal accident; Epidemic; Insect infestation |
| | Climatological hazard | A hazard caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability | Drought; Glacial Lake outburst; Wildfire |
| | Geophysical hazard | Also defined as geological hazard; a hazard originating from solid earth | Earthquake; Mass movement (dry); Volcanic activity |
| | Meteorological hazard | A hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days | Storm; Fog; Extreme temperature |

(*continued*)

**Table 2.** (*continued*)

| | Type of hazard | Definition | Main examples |
|---|---|---|---|
| | Extraterrestrial hazard | A hazard caused by asteroids, meteoroids, and comets as they pass near-earth, enter the Earth's atmosphere, and/or strike the Earth, and by changes in interplanetary conditions that effect the Earth's magnetosphere, ionosphere, and thermosphere | Impact; Space weather |
| | Hydrogeological hazard | A hazard caused to floods and landslides related to soil and land management | Flood; Landslide; Wave action |
| Man-made hazards | Technological hazards | A Hazard induced entirely or predominantly by human activities and choices. Industrial, transportation and miscellaneous hazards | Chemical-oil spill; Industrial explosion; bridge collapse; rail-road-air accident and so on |
| | Human hazards | Armed conflicts and other situations of social instability or tension | Civil disorder; Complex disaster-emergencies; Population movements; Cyber security; Terrorist event |
| NaTech | Mix | Technological accident caused by a natural hazard (Showalter and Myers, 1994) | Vajont Dam (Italy, 1963)<br>Forest fires in Indonesia (2015)<br>Landslide in Shenzhen (China, 2015) |

At this point, the central backbone taxonomy of the risk ontology has been put into evidence. However, to capture all the essential scientific information regarding a certain domain, also the relations between and among nodes need to be described. Indeed, additional relations better relate to the ontology's nodes and define the high-level architecture of the risk ontology. The specific relationships have been described via the "Object properties" panel.

Protégé allows the download of a multitude of plug-ins based on the various user's purposes. Figure 3 shows a scheme derived from the *OntoGraf* plug-in; in this case,

the user can only expand a selected relation or all of them simultaneously. However, browsing the ontology proceeds by incremental exploration since the whole expanded ontology cannot be displayed through automatic input; the only way is to click on all classes to expand each of them.

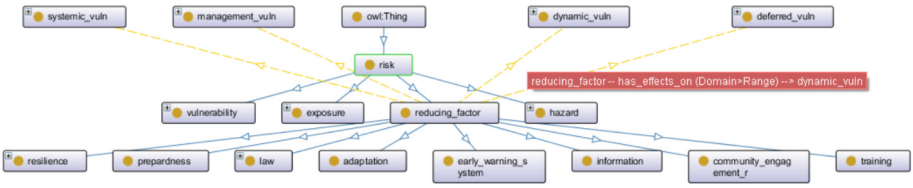



**Fig. 3.** OntoGraf scheme. Source: authors.

The reported examples demonstrate the benefits deriving from the use of the Protégé tool, serving as a comprehensive digital repository able to detail the relationships between terms, concepts, properties, and logical rules within a specific domain. Indeed, it provides support for graphical representations helping the users to identify information quickly and intuitively. Moreover, graphical representations help to understand the structure, observe the changes, and analyze the relationships between the various resources.

## 5 Discussion and Conclusions

Understanding the complex interaction between dynamic processes, societal factors, and physical hazards, which defines the concept of risk, is crucial for effective risk reduction and disaster management. Particularly, the multi-risk approach underscores the need for precise definitions and frameworks to analyze multi-risk environments effectively. Indeed, employing systematic frameworks like ontologies let the different stakeholders involved better identify, assess, and mitigate risks, ultimately enhancing resilience and reducing the adverse impacts of disasters. The improved understanding is ensured by a consistent level of semantic interoperability operating across different information systems and databases.

The Protégé tool provided a comprehensive organizational information scheme concerning the risk domain and captured the interactions between its components. It offered an intuitive and easy graphical representation and opportunities for further developments. The proposed application supports the possible integration of ontologies into decision support systems for disaster management and emergency response to changing environmental conditions and socio-economic factors. Therefore, ontological knowledge can be exploited to provide real-time recommendations, predictive models, and risk mitigation and management strategies.

Moreover, the level of cross-disciplinary collaboration is enhanced and subjected to improvements, bridging the gap existing between different disciplines and enabling experts to share knowledge and resources thanks to standard representations of risk-related concepts and relationships.

Overall, the proposed ontology aims to clarify definitions and relationships among elements that would otherwise remain unorganized, thus contributing to a better understanding and management of risks. Applying ontologies in urban and territorial planning could entail adopting an inter-scale approach that engages various institutional levels to ensure the compatibility and coherence of their planning tools. In such a scenario, enhancing the interoperability of geographic databases becomes crucial for promoting transparency and objectivity in institutional decision-making processes.

## References

1. Hariri-Ardebili, M.A.: Living in a multi-risk chaotic condition: pandemic, natural hazards and complex emergencies. Int. J. Environ. Res. Public Health **17**, 5635 (2020)
2. Weichselgartner, J.: Disaster mitigation: the concept of vulnerability revisited. Disaster Prev. Manag. **10**(2), 85–94 (2001)
3. UNISDR (United Nations International Strategy for Disaster Reduction). Living With Risk: A Global Review of Disaster Reduction Initiatives. United Nations, Geneva (2004)
4. UNISDR (United Nations International Strategy for Disaster Reduction Terminology on Disaster Risk Reduction). www.undp.org/sites/g/files/zskgke326/files/migration/ge/GE_isdr_terminology_2009_eng.pdf, (Accessed 15 Feb 2024)
5. Blaikie, P., Cannon, T., Davis, I.: At Risk: Natural Hazards, people's vulnerability and disasters. Routledge, London (1994)
6. United Nations Development Programme / Office of the United Nations Disaster Relief Coordinator (UNDP/UNDRO) Disaster Management Training Programme. An Overview of Disaster Management, 2nd ed. United Nations, Geneva (1992)
7. Johannesburg Declaration on Sustainable Development, https://digitallibrary.un.org/record/499757, last accessed 2024/02/15
8. Bell, R., Glade, T. Multi-hazard analysis in natural risk assessments. In: Brebbia, C.A. (ed.), International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation, Rhodes, Greece, pp. 197e206 (2004)
9. Glade, T., von Elverfeldt, K.: MultiRISK: an innovative concept to model Natural Risks. In: Oldrich, H., Fell, R., Coulture, R., Eberhardt, E. (eds.) International Conference on Landslide Risk Management, 31 May – 03 June 2005, Vancouver (CND), Balkemaa, pp. 551–556 (2005)
10. Kappes, M., Keiler, M., Glade, T.: From single- to multi-hazard risk analyses: a concept addressing emerging challenges. In: Malet, J.P., Glade, T., Casagli, N. (eds.), Mountain Risks: Bringing Science to Society. Proceedings of the International Conference, Florence, pp. 351e356. CERG Editions, Strasbourg (2010)
11. Kappes, M.S., Keiler, M., von Elverfeldt, K., Glade, T. Challenges of analyzing multi-hazard risk: a review. Nat. Hazards, **64**(2), 1925e1958 (2012)
12. Komendantova, N., et al.: Multi-hazard and multi-risk decision-support tools as a part of participatory risk governance: Feedback from civil protection stakeholders. Int. J. Disaster Risk Reduct. **8**, 50–67 (2014)
13. Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., Marcomini, A.: A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. J. Environ. Manage. **168**, 123–132 (2016)
14. Carpignano, A., Golia, E., Di Mauro, C., Bouchon, S., Nordvik, J.P.: A methodological approach for the definition of multi-risk maps at regional level: first application. J. Risk Res. **12**(3–4), 513–534 (2009)
15. Gruber, T.R.: A translation approach to portable ontology specifications. Knowl. Acquisition, 199–220 (1993)

16. Protégé OWL Tutorial, http://130.88.198.11/tutorials/protegeowltutorial/, last accessed 2024/02/15
17. Scolobig, A., Komendantova, N., Mignan, A.: Mainstreaming multi-risk approaches into policy. Geosciences **7**(4), 129 (2017)
18. Abedin, A., Shaw, R.: The role of university networks in disaster risk reduction: perspective from coastal Bangladesh. Int. J. Disaster Risk Reduct. **13**, 381–389 (2015)
19. Matsuura, S., Razak, K.A.: Exploring transdisciplinary approaches to facilitate disaster risk reduction. Disaster Prevent. Manag. Inter. J. **28**(6), 817–830 (2019)
20. World Economic Forum The global risk report 2023. 18th edition. ISBN-13: 978–2–940631–36–0 (2023)
21. International Federation of Red Cross and Red Crescent Societies. world disasters report 2022 trust, equity and local action Lessons from the COVID-19 pandemic to avert the next global crisis. Geneva (2023)
22. Mignan, A., Komendantova, N., Scolobig, A., Fleming, K.: Multi-risk assessment and governance. In: Madu, C.N., Kuei, C.H. (eds.) Handbook of Disaster Risk Reduction and Management, Chapter 14.World Sci. Press & Imperial College Press: London, UK, pp. 357–381 (2017)
23. Staab, S., Studer, R. (eds.): Handbook on Ontologies. IHIS, Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-540-92673-3
24. Gruber, T.R.: Toward Principles for the Design of Ontologies Used for Knowledge Sharing. Formal Ontology in Conceptual Analysis and Knowledge Representation, also available as Technical Report KSL-93–04, Knowledge Systems Laboratory. Stanford University (1993)
25. Murgante, B., Scardaccione G., Las Casas, G.: Building ontologies for disaster management: seismic risk domain. In: Krek A., Rumor M., Zlatanova S., Fendel E.M. (eds.) Urban and Regional Data Management, pp. 259–269, CRC Press, Taylor & Francis, London (2009). https://doi.org/10.1201/9780203869352.ch23
26. Guarino, N., Giaretta, P.: Ontologies and knowledge bases: towards a terminological clarification towards very large knowledge bases. Knowl. Build. Knowl. Sharing **1**(9), 25–32 (1995). https://doi.org/10.1006/ijhc.1995.1066
27. Borst, W.N.: Construction of Engineering Ontologies for Knowledge Sharing and Reuse. PhD thesis, University of Twente, Enschede, Netherlands (1997)
28. Studer, R., Benjamins, V.R., Fensel, D.: Knowledge engineering: principles and methods. Data Knowl. Eng. **25**(1–2), 161–197 (1998). https://doi.org/10.1016/S0169-023X(97)00056-6
29. Guarino, N.: Formal ontology in information systems. In: Guarino, N. (ed.) Proceedings of the 1st International Conference-FOIS'98. Trento, Italy, 6–8 June, pp. 3–15. IOS Press, Amsterdam (1998)
30. Falquet, G., Mètral, C., Teller, J., Tweed, C.: Ontologies in Urban Development Projects. Springer-Verlag, London (2011)
31. Pietra, C.: Healthy City: an ontological understanding. PhD Thesis, Università degli Studi di Pavia, Pavia, Italy. 30 May 2022 (2022)
32. Ceusters, W., Smith, B., Flanagan, J.: Ontology and medical terminology: why description logics are not enough. In: Proceedings of the Conference: Towards an Electronic Patient Record (TEPR 2003). Medical Records Institute, Boston, Massachusetts (2003)
33. Métral, C., Billen, R., Cutting-Decelle, A., Ruymbeke, M.: Ontology-based approaches for improving the interoperability between 3D urban models. J. of Info. Tech. in Constr., **15** (2010)
34. Bennett, M.: The financial industry business ontology: best practice for big data. J. of Bank. Reg. **14**(3–4), 255–268 (2013). https://doi.org/68110.1057/JBR.2013.13
35. Gandon, F.: Distributed Artificial Intelligence and Knowledge Management: Ontologies And Multi-Agent Systems For A Corporate Semantic Web. PhD thesis. Université Sophia Antipolis, Nice, France, p. 86 (2002)

36. Musen, M.A.: The Protégé project: A look back and a look forward. AI Matters, vol. 1(4) . Association of Computing Machinery Specific Interest Group in Artificial Intelligence, (2015). https://doi.org/10.1145/2557001.25757003
37. Dudáš, M., Lohmann, S., Svátek, V., Pavlov, D.: Ontology visualization methods and tools: a survey of the state of the art. Knowl. Eng. Rev. **33**(E10), 2018 (2018). https://doi.org/10.1017/S0269888918000073
38. The International Disaster Database. Disaster Classification System. https://doc.emdat.be/docs/data-structure-and-content/disaster-classification-system/#fn:5, (Accessed 15 Feb 2024)