Decision Systems in Disaster Management with Application to Fire

Maria Bostenaru Dan, Cerasella Crăciun, and Adrian Ibric

Abstract This book chapter explores the utilization of an ontology of disaster images in the design of a decision support system for intervening in prevention or reconstruction efforts following events such as earthquakes, floods, and even fires. Grounded in philosophy, ontology in computer science relies on taxonomies, which are classifications of concepts used to facilitate object-oriented programming. To this end, existing collections of disaster images have been analyzed based on relevant literature. The objective here is to map the perception of disasters across different groups, including experts, the passive public, and actively affected individuals. These stakeholders play a crucial role in decision-making within a participatory planning framework, with the most advanced form being strategic planning. This approach offers an alternative to traditional urban regulatory and landscape planning. Urban planning and land use are essential considerations for non-structural disaster prevention interventions, particularly in areas where urban and wildland environments intersect. In such contexts, the coexistence of human settlements and forests in urban settings emphasizes the dual nature of forests as both natural heritage and a domain that calls for nature-based solutions.

Keywords Urban planning · Heritage · Photography · Ontology · Digital humanities

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J. Rodrigo-Comino and L. Salvati (eds.), *Fire Hazards: Socio-economic and Regional issues*, https://doi.org/10.1007/978-3-031-50446-4_6

1 Introduction

The vulnerability of urban or rur-urban areas, particularly at the urban–rural border, should be closely linked to the fragility of the sensitive quasi-/semi-natural, anthropic/constructed, and cultural landscape. This connection becomes essential when researching and planning for complex hazards, which involve combinations of factors that can exponentially increase cumulative risks (Crăciun, 2014). In 2010, a grant from the Canadian Centre for Architecture (CCA) supported research into the photographic expressions found in the CCA's collection of images depicting earthquakes, floods, fires, and even armed conflicts (Bostenaru, 2011a). The project seeks to establish a fresh perspective on the CCA's collection images in this thematic context, following several years of research. Most of these photographs are now available in digital format. Consequently, these photographs serve as a means to preserve and capture the moment of catastrophe in a way that the physical ruins themselves cannot.

The Romantic Movement's penchant for depicting ruins in art brought a focus on nineteenth century photography of such events. This exploration drew from the archives of the Canadian Centre for Architecture in Montreal, Canada. It aimed to juxtapose the perspectives of the past with contemporary views on the same issues, leveraging digital tools to do so. The photographers who contributed to this collection are also documented in nineteenth century photography history books held by the CCA. The analysis utilized a range of works from the collection, including those by Hannavy (2007), Blau and Kaufman (1989), van Veen (2010), Klett (2006), (1871), Barnard (1872), Peabody et al. (1899), Palazzoli (1981), Taylor (2007), Harris (1993), as well as a later exhibition by Bigiotti and Corvino (2015) and the book by Birken (2018) on the topic.

Numerous authors have explored the role of nature-based solutions and land use (Butsic et al., 2015; Chas-Amil et al., 2012; Galliana-Martin, 2017; Hanberry, 2020; Monteiro & Tavares, 2015; Nickayin et al., 2020; Parker, 2020; Price & Bradstock, 2013) in wildfire hazard prevention at the urban–wildland interface as non-structural measures in disaster risk management (Gociman, 2000). This book chapter proposes classifying and mapping these solutions using photography to facilitate related decision-making. However, among international photographic collections, the CCA stands out as a unique resource, even when compared to institutions like the Getty Museum, research and conservation institutes of foundations (https://www.getty.edu/art/collection/search?size=48&view=grid&q=fire), or ICCROM (the "International Centre for the Study of the Preservation and Restoration of Cultural Property" in Rome), which house several national resources of photographic collections. These include foreign academies like the British School at Rome (https://digitalcollections.bsr.ac.uk/islandora/search/fire?type=dismax), where a course on the Glasgow Library fire was held on May 9, 2016 (https://www.gsa.ac.uk/life/gsa-events/events/r/rising-from-the-ashes/?source=filter&type=27676/mackintosh)—an event attended

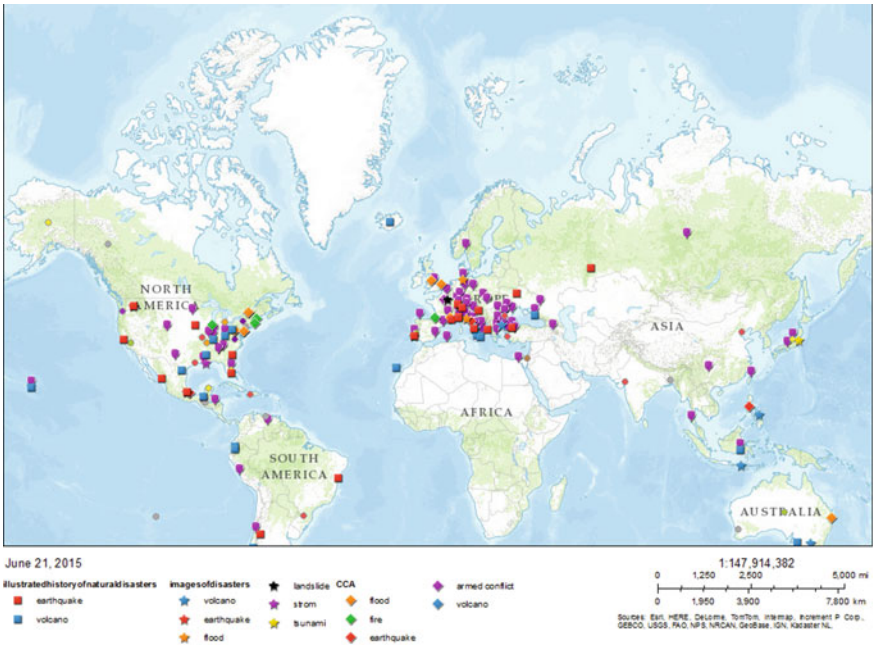


Fig. 1 Different hazards as mapped on the basis of the considered collections and databases (Bostenaru & Gociman, 2015)

by the first author. Other institutions, such as the American Academy in Rome (https://dhc.aarome.org/islandora/search/fire?type=dismax), and the collection at Bibliotheca Hertziana (https://foto.biblhertz.it/ete?action=queryFotos&desc=feuer+&refine=Suchen), have also contributed to the field. The CCA library's collection of books on the subject was also reviewed. An initial attempt to map these disasters is presented in Fig. 1.

The databases and collections included in Fig. 1 are as follows:

- The session series "Natural hazards' impact on urban areas and infrastructure," convened and co-convened by the first author over a period of 20 years at the European Geosciences General Assembly (1999–2000 convened by Friedemann Wenzel, 2001–2010 chaired and convened by the first author, see Bostenaru, 2011b). This series continued in 2023 after being co-convened by the first author as "Natural hazard impacts on technological systems and infrastructures" from 2013 to 2022 (for an overview, see session materials at https://meetingorganizer.copernicus.org/EGU2020/session/34881).
- Reviews of students supervised by the author as part of the course "Protection of settlements against risks" at the "Ion Mincu" University of Architecture and Urbanism. These reviews covered fires in the Mediterranean, Australia, and California and were presented at the COST action CA18135 webinar on May 5, 2021.

- A collection of historical photographs from the nineteenth century depicting various natural and man-made hazards, including fires (as shown in Table 1), sourced from the CCA.
- A collection derived from the exhibition and book on "Images of Disasters" (German research, Wieczorek et al., 2014), which includes major disasters throughout human history, providing an alternative to drawings through the use of photography.
- Another collection from one of the books, "Illustrated History of Natural Disasters" (Kozák & Černák, 2010), which covers major disasters from the dawn of civilization, similarly offering photographic representations.
- Additional works on architecture and catastrophes that were reviewed include "Tickle Your Catastrophe!" (Le Roy et al., 2011), based on the peer-reviewed proceedings of the conference with the same name held on March 6–7, 2009, in Ghent, Belgium. This conference included former CCA curator Dirk de Meyer.

A mapping of disasters is available as an app at http://www.arcgis.com/apps/Viewer/index.html?appid=6092a2d378404d6faab09b44a85f0aa2. This mapping draws a comparison between disasters mentioned in the CCA collection and those in various collections of disaster images, including books, exhibitions, or other visual data sources. This analysis is related to the examination of artistic photography using a method inspired by art historian René Berger (1963) for paintings and applied to cities by Kevin Lynch (1960). Berger's book primarily analyzes paintings, but the method, focused on understanding proportions and composition elements, can be applied to any type of image, including photographs. Lynch's work, on the other hand, mapped the perception of urban areas by categorizing elements of urban texture into landmarks, zones, paths, edges, and nodes. These categories are used to create mental maps when navigating a city.

Lynch's method has been adapted for landscapes by Popa (2014), making it suitable for aerial views, which constitute a significant portion of the images in the CCA collection. Popa (2014) views photography as a tool for preserving the memory and

Table 1 Fire events in the CCA collection

Known photographers who photographed such subjects	Individual events
J. Andrieu	Boston 1860, USA
Edouard Baldus	St. Claude, France
George N. Barnard	Paris (Commune), France
James Wallace Black	Philadelphia, USA
Robert Burley	Louisiana, USA
Alfred Capel-Cure	Notre Dame de Montréal, Canada
Franck	Chicago, USA
Frederick Gutekunst	Quebec, Canada
Brian Merrett	Illinois, USA
A. Richebourg	Portland (Maine), USA (stereo)
C. Seaver Jr	
John P. Soule	
William Notman & Son	

identity of landscapes, encompassing both natural and urban environments. This adaptability makes it suitable for analyzing urban landscapes affected by disasters, where visible changes are often documented in before-and-after photographs. Mental maps play a crucial role in risk perception, particularly in post-disaster reconstruction efforts, where preserving the heritage habitat (as defined by Gociman, 2000) is a priority. Another related mapping method from the 1950s, developed by Guy Debord (1955), laid the foundation for psycho-geography. This method is still used in contemporary urban analyses, including those within the COST action 18,126, in which the first author is involved. The upcoming steps in the analysis, as shown in Fig. 2, follow an ontology previously developed by the author (published in Bostenaru, 2011a) and are based on the elements of nature that cause disasters, as explained later.

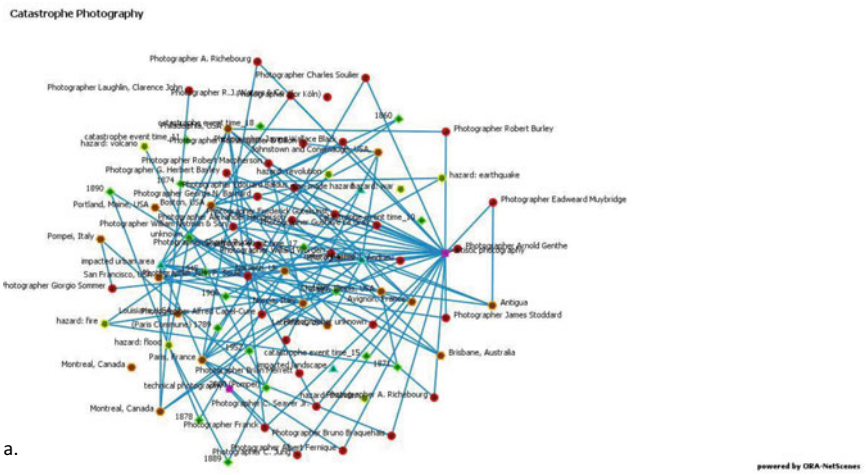
2 Ontologies Review

Rehbein (2017) discusses the modeling of data in ontologies in a digital humanities textbook. Another approach by Timothy Tambassi (2018, 2021) establishes a connection between ontologies in philosophy and those in computer science. Within the domain of geo-ontologies, philosophical considerations related to mapping are explored. In the context of urban studies, the COST Transport and Urban Development Action C21, known as "Towntology—Urban Ontologies for Improved Communication in Urban Civil Engineering Projects," has addressed urban ontologies. Simultaneously, several ontologies have been developed for the field of architecture. An early effort by Sandaker (2010) focuses on the ontological representation of structures, a topic also relevant to disaster management given that structural failures are a primary cause of building collapses during disasters. This ontological approach was even integrated into doctoral courses, such as E-ArchiDoct's Virtual Campus on post-master Studies in Architecture, a collaborative project involving 14 European Schools of Architecture, including the university of the authors and the Oslo School of Architecture and Design. Sandaker presented related content during the "Structures and Architecture" conference in Guimaraes, Portugal, in July 2010.

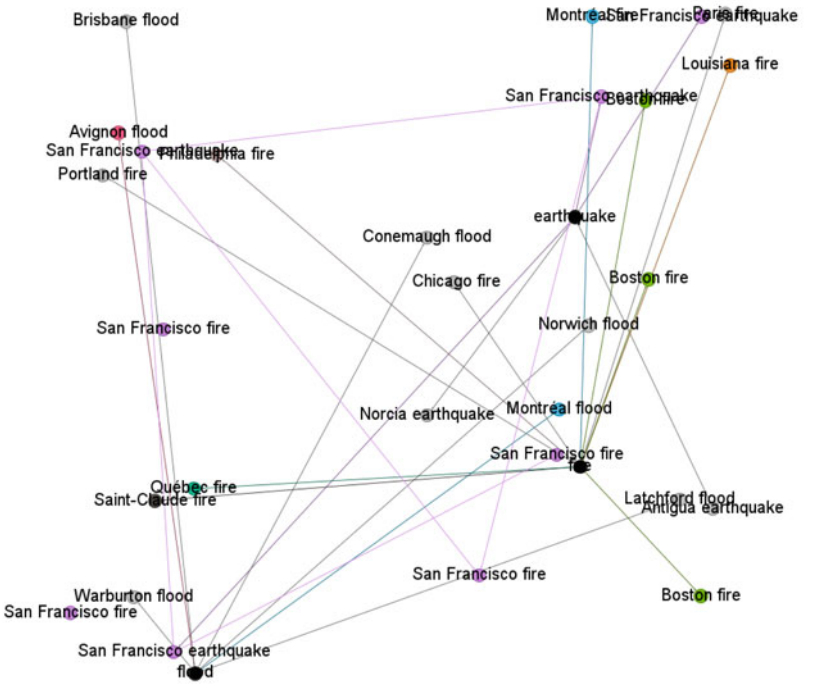
Cacciotti et al. (2013) explored how monuments' documentation can be represented using ontologies. This approach extended to Building Information Modeling (BIM) and Heritage Building Information Modeling (H-BIM), addressing monument damage information modeling within a system. Tibaut et al. (2018) also investigated how collections can be transformed into databases using ontologies, focusing on heritage buildings but excluding the disaster dimension.

These ontological approaches primarily focus on data modeling for interventions in existing buildings. However, it is worth noting that ontologies can also be applied to new building projects, as demonstrated by Pauwels et al. (2009).

The first author has contributed to several ontologies in various contexts. In the COST TU0801 project, titled "Semantic Enrichment of 3D City Models for Sustainable Urban Development," different 3-D models were analyzed to find an



a.



b.

Fig. 2 Network analysis of nineteenth century disaster photography at the CCA **a** with ORA software (Bostenaru & Armas, 2015), **b** ordered with Gephi software

optimal solution for the city of Lisbon. Additionally, within the Network for Digital Methods in Arts and Humanities, a European Science Foundation research network, the NeDiMAH ontology working group was established, and the NeDiMAH Methods Ontology (http://nedimah.dcu.gr/) was developed.

In a recent COST network focused on Underground Built Heritage, the EU project HERACLES ontology (Hellmund et al., 2018), which addresses climate change disaster mitigation, was examined. An ontology was also created to organize disaster images (Bostenaru, 2011a). Furthermore, cost modeling for retrofitting in disaster prevention or post-disaster scenarios was centralized within VuWiki (Khazai et al., 2014), a Wiki platform for vulnerability information developed for the Global Earthquake Model socioeconomic component (https://storage.globalquakemodel.org/what/physical-integrated-risk/socio-economic-vulnerability/). Another contribution to the Global Earthquake Model involved the GEM Building Taxonomy Version 2.0 (https://www.globalquakemodel.org/single-post/2017/05/17/GEM-Building-Taxonomy-Version-20). This contribution entailed converting reports from the World Housing Encyclopedia initiative of the Earthquake Engineering Institute, which managed this component, into the taxonomy format. During this conversion process, the World Housing Encyclopedia's questionnaire was transformed into a taxonomy to serve as a foundational component for an ontology.

3 Results

Wildfires that affect urban areas are a critical subject within the broader field of vegetation fires, particularly forest fires. In English, they are commonly referred to as wildland fires in the wildland–urban interface (WUI). This interface represents the region where construction, especially residential development, is situated within or close to flammable vegetation. It is the area where wildfires pose the most significant risk to human populations, making it highly vulnerable due to the potential for human casualties. In many Central European countries, this specific topic has not received extensive research attention. While the risk in these regions is generally lower compared to Mediterranean countries, there are still areas that could be affected by wildfires, such as cities in Romania (e.g., Brașov, Piatra Neamț). Typically, these areas consist of clustered urban development with less interspersion with forests. Nevertheless, the potential risk exists and offers a valuable avenue for research (Lorenţ et al., 2018, 2022; Mallinis et al., 2019).

The National Institute for Research and Development in Forestry "Marin Drăcea" (INCDS) has included general protection measures against these fires in the Simplified Procedure conducted as part of The Romanian Operational Programme "Administrative Capacity," a structural instrument in forestry (SIPOCA 395 Project, 2021). This program, which implements the European Social Fund (ESF) during the 2014–2020 period, focuses on "The implementation and development of common systems and standards to optimize decision-making processes in the field of water and forests." It aims to apply an evidence-based approach to policymaking in the Ministry

of Water and Forests and to systematize and simplify legislation related to water and reduce administrative burdens for businesses operating in the forestry sector. This program also addresses the interface area between the natural and built environment.

From an urban planning perspective, fires occurring at the urban–wildland interface impact the urban periphery. The Landscape Forum Le Notre dedicates a whole section to the urban periphery, and Stan (2013) discussed its current state. During the Modern Movement, the urban periphery gained special significance with the development of "Siedlungen," a German term referring to groups of small housing buildings located in the outskirts of cities. This approach not only introduced a new urban planning paradigm but also had implications for fire hazards. Unlike traditional urban blocks, the "Zeilenbau" concept emerged, characterized by the arrangement of long, narrow residential buildings perpendicular to the main street, each self-standing within green spaces. This layout had a different impact on the spread of fires due to the arrangement of buildings in relation to each other and to surrounding vegetation. While notable fires have affected individual buildings, including those from various architectural eras like the Middle Ages and Art Nouveau, urban fires capable of affecting entire areas, which can now be simulated thanks to increased computing power, can also be caused by wildfires. Urban and territorial strategies applied to landscape planning can effectively contribute to the resilience of complex integrated landscapes, encompassing quasi-/semi-natural, anthropic, and cultural elements. These landscapes can serve as both promoters and models for intervention strategies, representing a unique institutional form of urban and territorial management and planning (Crăciun, 2010).

Today, we are witnessing processes through which it is necessary to foresee possible "*Black Swan*" type events (Taleb, 2007) and to integrate vulnerabilities and the impact of the highly improbable, in the process of strategic planning of complex hazards, both at the European, regional, cross-border or territorial level, and at the local level of detail, on spatial urban design and landscape planning research, study, projects, and strategic regulations (Crăciun, 2021). The identification of areas with potential risk and the impact on the landscape and the urban life framework is necessary to be based on a specific methodology (Crăciun, 2009–2012, Fig. 3) of vulnerabilities to minimize the possible risks and identify the specific types of hazard and vulnerabilities relevant to the processes of territorial and urban development in landscape (Crăciun, 2013).

A decision ontology is building on these approaches with ontology for buildings in case of disasters (Fig. 4).

Papalou and Baros (2019), Mikkola (2008), and Papathoma-Köhle et al (2022) have provided valuable insights into how criteria weighting in decision trees can be performed. Papalou and Baros (2019) extend the common post-disaster rapid visual screening method, primarily used for earthquakes, to include fire hazards. They provide an example from a 2018 fire in Greece, assessing its impact on various building types, including concrete, masonry, timber, and steel skeleton structures. This approach, which considers structures based on their material composition, is a characteristic feature of the rapid visual screening method. Mikkola (2008) also

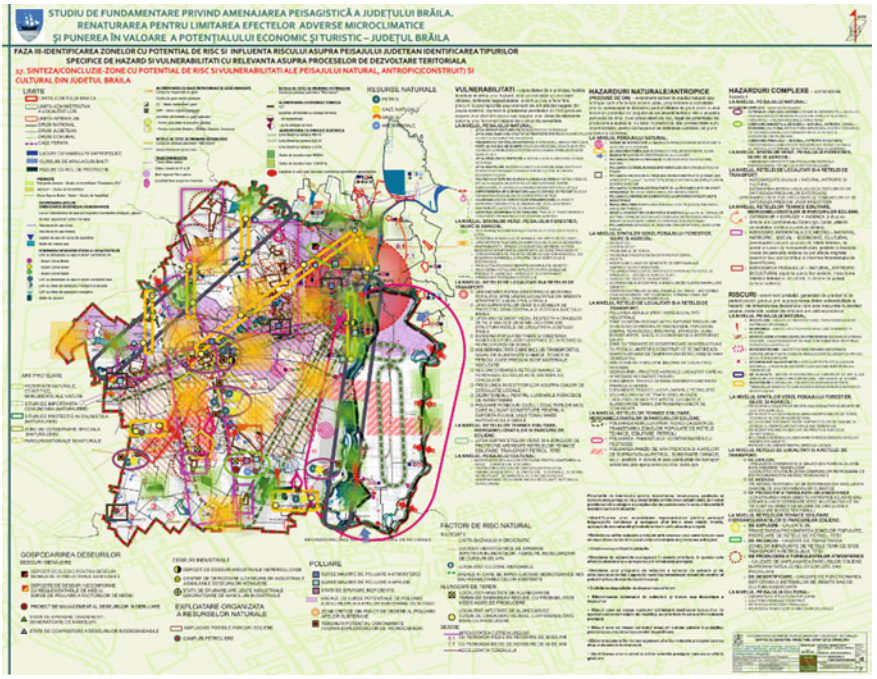
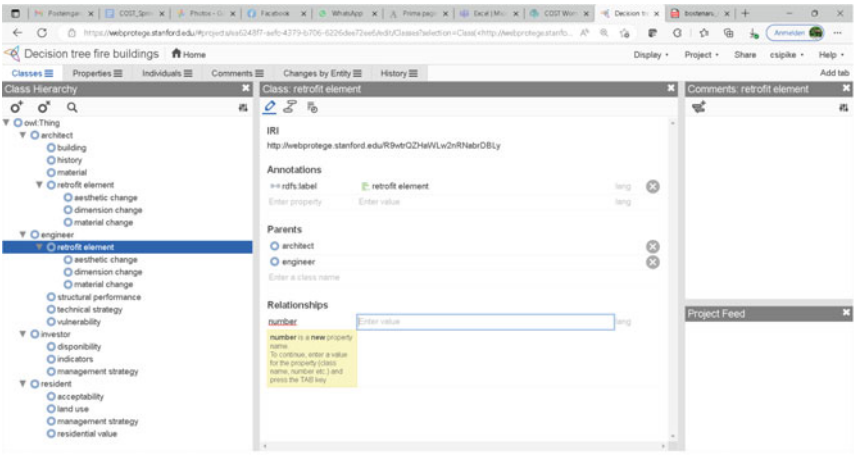


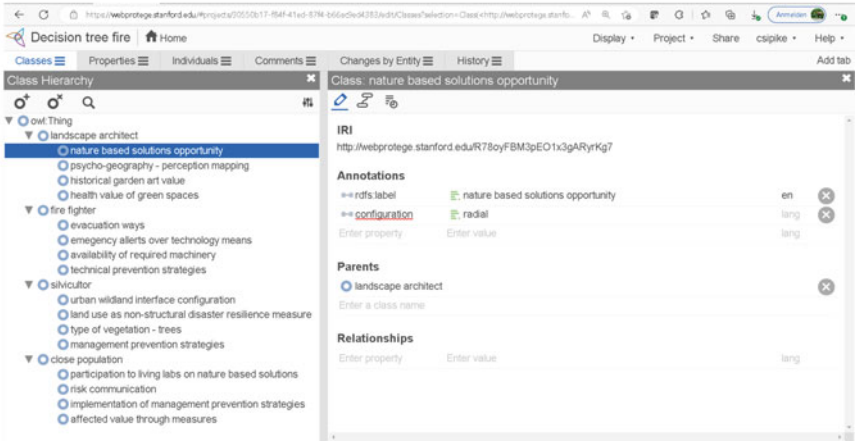
Fig. 3 Urban Territorial Masterplan nr. 17: Conclusions Synthesis—Areas with potential risk and vulnerabilities of the natural, anthropic/urban and cultural landscape in Brăila County, Romania, from research and applied case study project: New Methodological Integrate Complex Research of the Macro-and Mezzo-Scalar Level of the Natural, Anthropic and Cultural Landscape, Center for Research, Design, Expertise and Consulting of Bucharest "Ion Mincu" University of Architecture and Urbanism, Vol. III, pp.112–124 (*Source* Crăciun, Cerasella [2009–2012])

takes into account building materials but, prior to that, explores the effects of wildfires on buildings located at the urban–wildland interface. Drawing insights from a European project, this research not only examines how fires affect buildings and building materials but also investigates the mechanisms by which fires propagate toward buildings. It is worth noting that this research delves into impact assessment, a topic also covered in the mapped European Geosciences Union session. Additionally, the seminar works of students in the course have been included in the overview mapped in Fig. 1. Some of these presentations specifically focus on fires in the Mediterranean region, the USA (California), and Australia, aligning with the themes introduced by Papathoma-Köhle et al (2022).

Papathoma-Köhle et al (2022) emphasize the significance of the urban–wildland interface in the context of decision-making, aligning with the objective of this taxonomy. They also note that research on the vulnerability of the built environment to wildfires has been limited. To develop indices, they draw on a well-documented wildfire event, including one that occurred in Greece in 2018. Their approach differs from



a.



b.

Fig. 4 Decision ontology **a** multihazard ontology, **b** surroundings

the papers discussed earlier in that, in addition to structural type and building material—the literature review on physical vulnerability indexes also incorporates other factors like roof type. Moreover, they consider the relationship between buildings and their surroundings to assess the response of buildings to wildfires.

Figure 4b in our ontology primarily focuses on the surroundings, while rapid visual screening, as presented by Bektaş and Kegyes-Brassai (2022), is integrated into the multihazard ontology depicted in Fig. 4a. Future approaches should also consider interior furnishings, as highlighted in the discussion by Papathoma-Köhle et al (2022). Although we have partially addressed emergency response aspects in our work, they remain essential considerations.

Rapid visual screening can be adapted to different geographic regions based on architectural characteristics, as demonstrated in projects like Risk-UE for the Mediterranean region and Romania (Mouroux & Le Brun, 2008). Regarding the ontology section related to the building–surroundings relationship at the urban–wildland interface, we have developed weighting and indices, as required by the ontology. To determine these, we utilized the AHP MCDM method proposed by Saaty (1980). By categorizing vulnerability indicators into the two blocks, as also done by Papathoma-Köhle et al. (2022), our method covers a more extensive range of criteria—four times more. These criteria are grouped within the stakeholders' decision tree, streamlining the decision-making process. Ultimately, this decision-making process aids in retrofitting efforts, and some of the reviewed papers, including our method, can be instrumental in conducting cost–benefit analyses.

4 Conclusion and Final Remarks

We have examined the general approach to nineteenth century photography of disasters, encompassing urban photography series, stereo photography (as featured in scholars' selections), and the contemporary use of historic photographs in before-and-after comparisons. Numerous digital humanities centers house collections of catastrophe photographs, including those associated with foreign institutions in Rome, such as the Bibliotheca Hertziana, American Academy in Rome, and British School in Rome. The digital art history initiatives of the Getty Foundation have also sponsored courses on methods for working with images. Analyzing these images represents just one facet of a more comprehensive research project. As part of this project, the author intends to analyze their own images of endangered or resilient buildings using image analysis techniques such as mapping (including network mapping) and image annotation (using tools like ImagePlot, Netline, and Palladio). An ontology proves invaluable for categorizing images within a collection and organizing them into a database.

Increasingly, European projects are developing computer-supported decision systems to address climate change and the impact of other disasters on built and natural heritage. Recent examples include STORM, HERACLES, and ongoing projects like ARCH, SHELTER, and HYPERION, among others. In most cases, the starting point for designing these computer systems, often involving Internet of Things (IoT) approaches, is the ontology. In the author's project, the aim is to utilize images of monuments and sites from the first half of the twentieth century to draw lessons from vernacular architecture, which had a historically proven eco-adaptation. These lessons will inform the design of locally adapted retrofit solutions to mitigate hazards like wildfires in contemporary global contexts. During that period, the challenge was to build affordably and socially, leading to constructions in peripheral areas near forests. Today, environmental concerns drive change, with nature-based solutions being particularly relevant for addressing fire disasters, whether in urban

settings adjacent to forests or in eco-architectural designs to protect materials from heat. This approach covers both aspects of the decision system we propose.

Acknowledgements The authors would like to acknowledge the support of the Exploratory research project "Future on the past," funded by UEFISCDI Grant agreement no. PN-III-P4-PCE-2021-0609.

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