Advances in Sustainability Science and Technology

Tiago Miguel Ferreira *Editor*

Multi-risk Interactions Towards Resilient and Sustainable Cities

International

Springer

Advances in Sustainability Science and Technology

The book series aims at bringing together valuable and novel scientific contributions that address the critical issues of renewable energy, sustainable building, sustainable manufacturing, and other sustainability science and technology topics that have an impact in this diverse and fast-changing research community in academia and industry.

The areas to be covered are

- Climate change and mitigation, atmospheric carbon reduction, global warming
- Sustainability science, sustainability technologies
- Sustainable building technologies
- Intelligent buildings
- Sustainable energy generation
- Combined heat and power and district heating systems
- Control and optimization of renewable energy systems
- Smart grids and micro grids, local energy markets
- Smart cities, smart buildings, smart districts, smart countryside
- Energy and environmental assessment in buildings and cities
- Sustainable design, innovation and services
- Sustainable manufacturing processes and technology
- Sustainable manufacturing systems and enterprises
- Decision support for sustainability
- Micro/nanomachining, microelectromechanical machines (MEMS)
- Sustainable transport, smart vehicles and smart roads
- Information technology and artificial intelligence applied to sustainability
- Big data and data analytics applied to sustainability
- Sustainable food production, sustainable horticulture and agriculture
- Sustainability of air, water and other natural resources
- Sustainability policy, shaping the future, the triple bottom line, the circular economy

High quality content is an essential feature for all book proposals accepted for the series. It is expected that editors of all accepted volumes will ensure that contributions are subjected to an appropriate level of reviewing process and adhere to KES quality principles.

The series will include monographs, edited volumes, and selected proceedings.

Tiago Miguel Ferreira
Editor

Multi-risk Interactions Towards Resilient and Sustainable Cities

Springer

Editor
Tiago Miguel Ferreira
School of Engineering, College of Arts,
Technology and Environment (CATE),
University of the West of England
(UWE Bristol)
Bristol, UK

ISSN 2662-6829 ISSN 2662-6837 (electronic)
Advances in Sustainability Science and Technology
ISBN 978-981-99-0744-1 ISBN 978-981-99-0745-8 (eBook)
https://doi.org/10.1007/978-981-99-0745-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

This book is dedicated to multi-hazard studies, including essentially seismic, flood, urban fire and landslides.

It starts with Chapter 1, introducing the topic of multi-hazard and their interactions towards a resilient and sustainable society, and its importance in urban planning and development.

Chapter 2 is dedicated to methods and tools for evaluating individual risks and managing them in the context of an urban area. Cascading effects are then introduced as multi-hazards of modern urban areas of complex interactions. The authors present two approaches to analyse the problem, the qualitative and semi-quantitative methodologies to represent risks, the first based on thresholds and the other on indexes. Climate change has been brought into the context of index terminology. The authors prefer the second one for reasons of better population perceptibility. Then, they introduce the scale of analyses, one of the most important parameters when we deal with the geography territory.

Chapter 3 is dedicated to the analysis of what the authors call social vulnerability using a large number of social indexes. Illustrations of the developments in this chapter and all the others are made through an application to the Lisbon Metropolitan Area (LMA). But the concepts could be used in any other territory with similar constraints.

Chapter 4 is dedicated to flood risk assessment in the LMA, Chapter 5 is to fire susceptibility and Chapter 6 is to seismic vulnerability (excluding tsunami, which will be dealt with in Chapter 8) and risk assessment.

Chapter 7 analyses landslide hazards by the Analytic Hierarchy Process (AHP) methodology.

Final Chapter 8 is tentative to consider the multi-hazard susceptibility assessment in the land use planning of LMA, also considering the tsunami, coastal erosion and cliff retreat in a climate change environment.

The book is intended to fulfil various audacious objectives considered individual risks and in a global multi-hazard panorama. It pretends to be a helpful text for scientists not familiar with other topics of the multi-hazard collection besides their own and a practical guideline for end-users and stakeholders, mainly practitioners and decision-makers.

The book is well-balanced among the topics above, and the new jargon is a good complement for some readers and an introduction to others.

The application to LMA is an excellent choice as we are in a larger urban area with a mix of the highly concentrated population and the less populated area, zones with an ancient patrimony and new moderate size, 10-15 stories high modern buildings. Social vulnerability is a topic of great importance that governs most possible hazards and significant risks and impacts.

The unit of work changes from hazard to hazard, being the county in some cases or parishes in others, or at the urban block/susceptibility area level as in a detailed analysis of landslides, reflecting the authors´ experience. While Census block information is the primary data source to analyse social vulnerability, urban fires are studied at the parish level. Urban types of equipment are based on a radius of influence used to define criticality through principal component analyses (PCA). Finally, aggregation on counties is made.

Census data may not be the most qualified source of information because the parameter values depend very much on the preparation and prior knowledge of the agents doing it, and sometimes apparent errors are committed, especially if we talk of a large scale of study. Most probably, we can use Artificial Intelligence/Machine Learning (AI/ML) shortly to help in decreasing uncertainty on census data gathering. As an example, we can say that AI/ML can help in identifying in a building the number of stories, the epoch of construction/rehabilitation, the state of conservation, etc. speeding the data-acquiring system and reducing budgets.

In addition, the quality of the final results depends on the detailing techniques used in the individual studies. There are cases of simulation where we can validate the models using past events, which should be exercised whenever possible. Still, there are other cases where it is not easy to calibrate the models.

A question that arises in many texts dealing with various types of hazards is the meaning of terminology/glossary/taxonomy, which has not yet been accepted worldwide. On the contrary, we keep seeing different terms to designate the same phenomenon, and some confusion may arise among specialists in a specific hazard. Lately, with the introduction of new topics about various hazards, the situation may be worse. The Glossary of UNESCO serves this moment to give a minimum understanding of different hazards and risks. Still, in the future, we badly need a better and more complete series of terms to attain more consistency. Specialized terminology is already available in several areas, such as the case of the Global Earthquake Model (GEM), which is very much oriented to earthquake engineering, whereas the United States Geological Survey (USGS) goes to geological Hazards.

An extensive collection of papers organized by chapters (40 on average with repetitions) completes the text. Each chapter is a text that can stand by itself, useful for individual interest reading. So that if someone only wants to look into a single topic, this chapter does not require the reading of other chapters. This option, made by a great team of experts in the territory's geography, creates repetitions on the main description of LMA.

I want to call attention to the problem of multi-hazard that LMA already suffered during the 1755 Lisbon earthquake, which was probably one of the first areas struck by a series of multi-hazard events that started with a series of significant intensity and long duration ground shakings causing the failure of a large number of collapses. A strong tsunami followed within tens of minutes and devastated a large area downtown. The tragedy continued with an urban fire that was difficult to extinguish due to the precarious damage and lack of means to fight. More hazards can be associated with events like this, such as the liquefaction of particular soils and even the existence of landslides in the hills of greater inclination. Overall, the 1755 event caused the LMA an estimated number of victims in the order of 20 000 to 40 000 persons out of a population of 150 000-200 000 and caused significant impacts in Spain and Morocco. For Portugal, the estimate is 50 to 100% of the GDP at the epoch.

In terms of the impact on the constructed park, 30% collapsed, 30% was inhabitable, 30% could be used with great caution, and only 10% was in conditions of being occupied.

Carlos Sousa Oliveira
Professor Emeritus
Instituto Superior Técnico
Lisbon, Portugal

About This Book

Over the past years, a considerable volume of work has been conducted to assess urban risks resulting from individual natural hazards. However, assessing the probable cumulative impacts of multiple hazards has not yet entered the mainstream of research and urban management practice, which represents a significant drawback in the current climate change context. This book aims to contribute to tackling this issue by offering a comprehensive discussion of the various stages involved in identifying, assessing, and managing multi-hazard risk in urban areas—covering from the identification and characterisation of the exposed elements to the analysis of the impact of individual hazards (including earthquake, flood, fire, and landslide) and the assessment and management of risk posed by multiple hazards in a climate change context. After being presented in a clear and structured way, all the concepts and approaches addressed in the book are applied to the Lisbon Metropolitan Area, one of the most vibrant and dynamic metropolitan areas of the globe, allowing for an applied understanding of the covered topics. Besides offering solid theoretical grounding, this book provides practical guidelines on how the outputs coming from vulnerability and risk assessment approaches can be used to outline effective risk mitigation and emergency planning strategies, intending to be both a reference book and a practical guideline for end-users, including research scientists, practitioners, and decision-makers.

Contents

Editor and Contributors

About the Editor

Dr. Tiago Miguel Ferreira is a Lecturer in Civil Engineering at the School of Engineering of the University of the West of England (UWE Bristol), United Kingdom, and an invited Assistant Professor at the University of Coimbra, Portugal. Dr. Ferreira's research focuses on the structural vulnerability of historical buildings and urban areas to natural and anthropogenic hazards, specifically earthquakes, fires, floods, and landslides. More recently, he has expanded his focus to include the interaction between different hazards and both physical and social vulnerability, both in the context of single, compound and cascading hazards. Recognised as among the 2% top-cited scientists in the world by Elsevier BV and Stanford University (2021 and 2022) twice, Dr. Ferreira is a highly accomplished academic in his fields of expertise. He has co-authored nearly 200 scientific and technical publications, including dozens of research articles in some of the most reputed international journals. He has also edited several books on the topics of vulnerability and risk assessment and participated in and coordinated many research projects in these fields. Currently, Dr. Ferreira is a co-Editor-in-Chief of 'GeoHazards', a multidisciplinary journal devoted to theoretical and applied research across the whole spectrum of geomorphological hazards, and a Section Editor-in-Chief of 'Fire', a wide-spectrum journal about the science, policy, and technology of fires and how they interact with communities and the environment.

Contributors

Ana Cardoso Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

José Carlos Domingues Institute for Sustainability and Innovation in Structural Engineering (ISISE), Department of Civil Engineering, University of Minho, Guimarães, Portugal

Tiago Miguel Ferreira School of Engineering, College of Arts, Technology and Environment (CATE), University of the West of England (UWE Bristol), Bristol, UK

Ricardo A. C. Garcia Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Paulo B. Lourenço Institute for Sustainability and Innovation in Structural Engineering (ISISE), Department of Civil Engineering, University of Minho, Guimarães, Portugal

Raquel Melo Institute of Earth Sciences, School of Science and Technology, University of Évora, Évora, Portugal

Sérgio Cruz Oliveira Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Carolina Pais Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Susana Pereira Faculty of Arts and Humanities, Geography Department, University of Porto, Porto, Portugal;
Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Eusébio Reis Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Pedro Pinto Santos Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Ângela Santos Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Teresa Vaz Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Maria Xofi Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands;
Institute for Sustainability and Innovation in Structural Engineering (ISISE), Department of Civil Engineering, University of Minho, Guimarães, Portugal

José Luís Zêzere Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal

Chapter 1
An Introduction to Multi-hazard Risk Interactions Towards Resilient and Sustainable Cities

Tiago Miguel Ferreira and Pedro Pinto Santos

Abstract The relationship between disaster resilience and sustainability in the context of urban risk has gained significant attention in recent years as the research and technical community work towards a safer, more sustainable way of living. Urban risk is a complex matrix that involves multiple elements at risk, hazards, temporal scales, and vulnerabilities, and this is why traditional risk assessment approaches that focus on addressing the impacts of a single hazard are inadequate for effectively assessing and managing urban risk, particularly in the current climate change context. With this in mind, the present chapter provides an introduction to the concept of multi-hazard risk and its relevance to resilient and sustainable cities by listing and briefly discussing the types of natural hazards that impact cities the most and examining the importance of risk assessment and management in reducing the risks posed by these hazards. The chapter also explores strategies for building resilience in cities, including the strengthening of physical infrastructure and the enhancement of social and economic resilience, and concludes by discussing future directions for research and practice in multi-hazard risk management for resilient and sustainable cities.

Keywords Multi-hazard risk · Risk assessment · Risk management · Resilience · Sustainable cities

---

T. M. Ferreira (✉)
School of Engineering, College of Arts, Technology and Environment (CATE), University of the West of England (UWE Bristol), Bristol, UK
e-mail: Tiago.Ferreira@uwe.ac.uk

P. P. Santos
Centre for Geographical Studies, Institute of Geography and Spatial Planning (IGOT), LA TERRA, University of Lisbon, Lisbon, Portugal
e-mail: pmpsantos@campus.ul.pt

T. M. Ferreira (ed.), *Multi-risk Interactions Towards Resilient and Sustainable Cities*, Advances in Sustainability Science and Technology,
https://doi.org/10.1007/978-981-99-0745-8_1

1 Introduction

Since the global framework for disaster risk reduction [44] was defined and approved in Sendai, Japan, there has been a greater focus on linking disaster resilience and sustainability through policies and tools that support risk-informed sustainable development. The relationship between the concepts of disaster resilience and sustainability in the context of urban risk has also been developing, and their role towards a safer, more sustainable way of living is now understood in a clear and more comprehensive way by the research and technical community working in this field [11].

Urban risk is a multi-dimensional matrix that often includes multiple elements at risk, such as people, buildings, and infrastructures, multiple hazards, multiple temporal scales, as well as multiple types of vulnerabilities. For this reason, unlike current practice, addressing the impacts of one single hazard is not sufficient when assessing and managing urban risk, and it is, therefore, necessary to replace current single-hazard approaches with multi-hazard risk assessment.

Multi-hazard risk refers to the potential impacts and consequences of multiple hazards on a particular location or system [24]. These hazards can be natural, human-induced, or socioeconomic in nature and may include events such as earthquakes, floods, landslides, fires, industrial accidents, terrorism, financial crises, and pandemics. Understanding and managing multi-hazard risk is critical for building resilient and sustainable cities, as it enables planners and policymakers to identify and assess potential hazards and vulnerabilities, develop risk management strategies, and implement measures to reduce the impacts of hazards on communities and infrastructure. In this chapter, we will be focusing particularly on natural hazards, although some of the considerations provided here also apply to other types of hazards.

The importance of considering multi-hazard risk in urban planning and development cannot be overstated. As extensively discussed in literature—see, for example, Lau et al. [25] or Pelling [33]—urbanization and population growth have led to the concentration of people and assets in cities, making them more vulnerable to the impacts of hazards. At the same time, cities also provide important economic, social, and cultural benefits, and are key drivers of global development and progress. Ensuring the resilience of cities is therefore essential for protecting communities, preserving economic, social and cultural assets [38], and promoting sustainable development.

This chapter aims to provide an introduction to the concept of multi-hazard risk and its relevance to resilient and sustainable cities—the topic of the project "MIT-RSC—Multi-risk Interactions Towards Resilient and Sustainable Cities", funded by the Portuguese Foundation for Science and Technology (FCT) under the MIT Portugal Program at the 2019 PT call for Exploratory Proposals in "Sustainable Cities", which was the basis for this book. The chapter begins by discussing the types of hazards that can impact cities and then discusses risk assessment and management strategies for reducing the impacts of these hazards. Finally, it concludes by exploring strategies for building resilience in cities, and identifies key directions for future research and practice in this area.

2 Natural Hazards in Urban Settings

Cities are exposed to a variety of hazards that can have significant impacts on communities and infrastructure. As mentioned earlier, these hazards can be natural, human-induced, or socioeconomic in nature, and can include very different types of events. Understanding the types of hazards that cities are exposed to is a critical first step in developing effective risk assessment and management strategies. Understanding the types of hazards that cities are exposed to is crucial for developing risk assessment and management strategies that effectively reduce their impacts. This is because specific hazards have different characteristics and impacts that need to be considered in the risk assessment process. As discussed in detail by Dickson et al. [10], tailored risk management strategies can then be developed based on the hazards that the city is exposed to. For example, a city exposed to earthquakes may need to focus on strengthening buildings and infrastructure, while a city exposed to floods may need to improve drainage and flood protection systems. This targeted approach helps to ensure that resources are used effectively and efficiently, as risk management measures will be focused on the hazards that pose the greatest risk to the city.

According to the Federal Emergency Management Agency [12], "*natural hazards are defined as environmental phenomena that have the potential to impact societies and the human environment*". These hazards, which are being increasingly influenced by climate change, can have significant impacts on cities, including physical damage to buildings and infrastructure, loss of life, and disruption of essential services. As previously mentioned, understanding the types of natural hazards that cities may be exposed to is essential for designing efficient risk assessment and management strategies. That is why it is probably worth including at this point a brief definition of the hazards that most commonly affect urban settings. It is also worth noting that the hazards listed below are the ones that will be addressed and discussed in greater detail in the following chapters of this book.

2.1 Earthquakes

Earthquakes are sudden, violent shaking of the ground caused by the movement of tectonic plates in the Earth's crust. They can cause damage to buildings and infrastructure, particularly in areas with a high concentration of unreinforced masonry or poorly constructed buildings (Fig. 1). Earthquakes can also trigger landslides, which can further damage buildings and infrastructure and block roads, disrupting transportation.

Fig. 1 Examples of urban masonry buildings damaged by earthquakes

Robert Mallet and John Milne were pioneers in studying how and why buildings were damaged during earthquakes. According to Cousins and Smith [7], on 13 October 1900, John Milne (1850–1913) wrote regarding his 1892 book on earthquakes: "*if you compare the contents of this volume with its reproduction, and a companion volume called 'Seismology' issued in 1898, you will realize the rate at which a neglected study is advancing*." In his observations, Milne noted that some societies had developed solutions for resisting earthquake damage and incorporated them into local construction practices, while in others, architects and engineers were unaware of the need to design for future shaking, a phenomenon that can be partially explained by the frequency of earthquakes in certain regions and the corresponding risk perception and seismic culture of the populations in those regions [27]. In his catalogue of destructive earthquakes [31], Milne estimated that over 12 million people had been killed by earthquakes in the 2,000 years prior to 1900. As noted by Bilham [7], he would have been astonished to see that, even with the advances in earthquake engineering that occurred in the century following his words, earthquakes would claim an additional 2 million lives.

2.2 Floods

Floods are the most frequent type of natural disaster and occur when an overflow of water submerges land that is usually dry. They can be caused by heavy rainfall, rapid snowmelt, or a storm surge from a tropical cyclone or tsunami in coastal areas. Depending on their extension and magnitude, floods can cause widespread devastation, resulting in loss of life and damage to personal property.

According to the United Nations Office for Disaster Risk Reduction [43], floods have affected more than 2 billion people worldwide between 1998 and 2017 alone (Fig. 2). People who live in floodplains or non-resistant buildings or lack warning systems and awareness of flooding hazards are particularly vulnerable to floods.

Fig. 2 Floods in Bingley, England, in 2015 (left) and in Venice, Italy, in 2018 (right)

Floods can also disrupt essential services, such as public health infrastructure, transportation, communication, and power, which can be particularly meaningful in urban areas, as discussed in great detail by Jha et al. [22] or Hammond et al. [19].

2.3 Landslides

Landslides, or mass movements, are the movement of rock, soil, or debris down a slope. As noticed by Alexander [2] in his pioneering article on urban landslides, landslides are often triggered by other hazards, such as earthquakes, storms, or heavy rainfall, and per se, rarely cause disasters that attract international attention. However, in many countries, smaller-scale landslide disasters, which involve damage valued at hundreds of thousands of dollars and may cause a few fatalities, are both numerous and frequent [2].

It is plausible to believe that the occurrence and impact of urban landslides will tend to increase in future due to two main reasons. Firstly, as a result of the pressures created by population growth—a topic that has already been widely treated in literature applied to different types of hazards; see, for example, Radeloff et al. [20], Hemmati et al. [21], He et al. [35]. Secondly, people are attracted to building on hillsides due to their natural beauty. In Olshansky's words [32], "*Hillsides pose unique problems for the construction and maintenance of human settlements. They are prone to natural hazards, and they topographically constrain the design of settlements. For these reasons, hillside lands often remain vacant long after adjacent valley floors are urbanized. Despite the constraints, they are attractive places to live because of the views and because of the sense of being close to nature.*" Thus, much urban expansion is expected to take place in hillside areas, and consequently, ground failure by landsliding will likely be one of the most significant geological hazards affecting urban settings in future [37].