BUILT HERITAGE IN POST-DISASTER SCENARIOS

IMPROVING RESILIENCE AND AWARENESS TOWARDS PRESERVATION, RISK MITIGATION AND GOVERNANCE STRATEGIES

EDITED BY
MARCELLO BALZANI
FEDERICA MAIETTI
MANLIO MONTUORI
FABIANA RACO

CRC Press
Taylor & Francis Group

BUILT HERITAGE IN POST-DISASTER SCENARIOS

It is assumed that the impact of natural and man-made hazards on society in terms of damage cannot be avoided. To reduce potential disaster levels and to assess which policies have had a positive outcome, a careful comparison should take place on the procedures implemented in the management of crises.

The experiences with the earthquakes in the Pianura Padana area and central regions of Italy in the last ten years have been incorporated in the 'After the Damages' advanced training project. This project aims to showcase recent innovations and advancements in post-disaster management, so as to take a more proactive role in post-disaster management, and to respond more effectively when disasters occur.

This volume provides insights into the dynamics and negative effects of natural and man-made hazards (i.e., earthquakes, fires, floods, droughts, volcanic eruptions, etc.), including more updated approaches to deal with post-disaster phases. The book also offers tools to deal with possible international crisis scenarios and mitigate the social impact of vulnerabilities through risk reduction.

Built Heritage in post-Disaster Scenarios aims at public administration managers, government agency representatives, international organizations, researchers, and professionals in architecture, engineering, and earth science.

PROCEEDINGS OF THE 1ST EDITION OF THE INTERNATIONAL SUMMER SCHOOL
"AFTER THE DAMAGES", FERRARA, ITALY, 1-15 JULY 2020

Built Heritage in post-Disaster Scenarios

Improving Resilience and Awareness Towards Preservation, Risk Mitigation and Governance Strategies

Edited by

Marcello Balzani, Federica Maietti, Manlio Montuori & Fabiana Raco

Department of Architecture, University of Ferrara, Italy

CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A BALKEMA BOOK

The International Academy "After the Damages" project has received funding from the Emilia Romagna Region in the scope of the three-year higher education projects in the cultural, economic and technological fields pursuant to art. 2 of the regional law n. 25/2018 approved by resolution of the Regional Council n. 1251/2019.

RegioneEmilia-Romagna

Front Cover Image: Finale Emilia, Modena, Italy. The parish church, commonly known as the Duomo, and its belltower seen from Via Del Monte on November 19, 2012 (©Manlio Montuori).

First published 2024
by CRC Press/Balkema
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by Integra Software Services Pvt. Ltd., Pondicherry, India

Design, composition and editorial coordination by Manlio Montuori

Library of Congress Cataloging-in-Publication Data

A catalog record has been requested for this book

ISBN: 978-1-032-18274-2 (hbk)
ISBN: 978-1-032-18275-9 (pbk)
ISBN: 978-1-003-25373-0 (ebk)
DOI: 10.1201/9781003253730

Built Heritage in post-Disaster Scenarios – Balzani et al. (Eds)

Table of contents

After the Damages Project Committees ix

Welcome Message xiii

Foreword xv

Preface xvii

Introductions xxiii

Rationalising the Emergency xxv

Existing Built and Cultural Heritage: Risk Prevention, Conservation and Management xxvii

Part 1: Invited lectures

Built heritage, natural hazards and climate change 3
M. Balzani

The aesthetics of landscape and the intervention on the historic city centers: The study of granada 17
J. Gallego-Roca

Public building restoration after earthquakes: A strategic overview of the funding process 27
D. Parisi

Temporary, non-invasive works 43
C. Di Francesco

3D digital cultural heritage for resilience, recovery and sustainability. The inception project 53
F. Maietti, M. Medici, E. Iadanza & F. Ferrari

Survey methods for the heritage and vulnerability values in a block of mexico city historic centre 65
S. Bertocci, M. Bigongiari & G. Dellabartola

DISS/Delta international sustainable strategies. An educational and research project for the Emilia-Romagna territory of the po delta 73
E. Dorato & R. Farinella

Overview several EU countries action versus pandemic emergency 83
D. Ganapini

Mind the_gap & Be Haz-Ior 93
S. Rossi & E. Castellaneta

Resilience of a legacy: Water harvesting in traditional settlements 99
M. Arya

Endangered heritage. The preservation of industrial artefacts in Abruzzo, through research and projects 109
C. Varagnoli, L. Serafini & C. Verazzo

Historic masonry building: From damage to first aid interventions 119
E. Coïsson & L. Ferrari

Building resilience: Documentating, surveying, and representing the historical urban contexts 129
P. Puma

Basics of the resilience of cultural heritage assets 141
R. Žarnić & B. Vodopivec

Critical-comparative analysis of the historical theatres in Emilia damaged by the 2012 Earthquake 151
M. Suppa

The damaged cemetery of Emilia-Romagna: From type definition to recurrent collapse mechanism identification 159
V. Vona

Analysis of damage mechanisms of fortified heritage and proactive information tools to prevent seismic risk 169
E. Zanazzi

Fostering economic and financial resilience through an ecosystem approach: Opportunities and peculiarities of cultural heritage 177
E. Borin

Documentation and damage prevention in conflict areas: The acheiropoietos monastery, cyprus 185
A. Camiz

Integrated systems for deformation monitoring 195
E. Falvo, F. Grassi, P. Rossi, L. Parente & A. Capra

Risk management for historic houses museums: Casa de Rui Barbosa, Rio de Janeiro, Brazil 205
C.S. Rodrigues de Carvalho

Environmental disasters in Brazil: Case studies - cities of São Luiz do Paraitinga and Goyaz Velho 211
J.G. Simões Junior

Reclamation plants between history and conservation: The effects of the 2012 earthquake 215
A.M. Tralli

Preliminary knowledge in post-earthquake interventions. The case studies of Navelli-Civitaretenga (AQ) and Codiponte (MS) 225
C. Vernizzi

Emergency management: Awareness, knowledge and communication after the Emilia earthquake in 2012 237
A. Sardo

Part 2: Thematic lectures

From disaster to community restoration through interventions on the historical and artistic heritage 245
A. Libro

Palazzo Schifanoia in Ferrara 247
N. Frasson, A. Libro, M.L. Laddago, F. Pozzi & M. Roversi

Collegiate church of Santa Maria Maggiore in Pieve di Cento 267
R. Gabrielli, M. Oprandi, M. Boni, A. Libro & M.L. Laddago

Duomo of Santa Maria Maggiore in Mirandola 283
G. Azzolini, A. Libro & M.L. Laddago

Palazzo Sartoretti in Reggiolo 311
M. Goldoni, F. Camorani, F. Ferrari, G. Malaguti, A. Libro, M.L. Laddago & R. Angeli

Mapping the cultural regeneration. The pilot experience of the "Crateri" project 337
N. Marzot & L. Bolelli

Public space and landscape: Recovery strategies and risk mitigation for the management of disaster events 345
C. Pescosolido

Protocol for an integrated 3D survey for cultural heritage at risk 359
F. Raco

The post-disaster legacy in Italy and the effects unfolded by the reconstruction plans 367
M. Montuori

Part 3: Multiscale application and simulation Workshop

Knowledge for conservation. Methods and technologies to preserve the cultural heritage 387
S.S. Jawhar, R. Del Regno, Z. Megouar, M. Perticarini & S. Morena

Team-driven documentation of civil structures 397
C. Callegaro, R. Garozzo, E. Magrinelli & Y.A. Mazurek

Floods and heritage: Comparison of cases and observations 405
C. Tosto, I. Amani, L. El Mokhlis, M.I. Lattarulo & S. Mhatre

ME.MO.RIA - monuments essence, materials observation, risk interpretation & analysis 417
R. Bernardello, O. Buscariolli, M. Felli, H. Gallo, B. Letizia & E. Ziraldo

Faster! Platform: Fast assessment and survey of the territory for evaluation and restoration 427
R. Campiotto, N. Pini, F. Ridolfi & C. Ornelas

Contemporary approach to ancient walls 435
L. Ainine, M. Cornieti, I. Manetta, Ö. Özkuvanci & G.C. Santangelo

A thrust on modern heritage conservation: The comparative cases of 20th century architecture in India, Italy and Turkey 447
C. Sharad, G. Bufo & Z. Önsel Atala

The dimensions of heritage as strategies for action plans for pre and post disaster intervention 455
A. Milano, F. Graziosi, I. Valle Herrero, J. Krholing Peruzzo & M. Lidón de Miguel

Strategies to manage flooding risk in historical cities: The case of Paraty 465
L. Praticò, I.S. de Serro Azul, M. Vaz De Souza, M. Previti & A. Ledo Marques

Author index 477

Built Heritage in post-Disaster Scenarios – Balzani et al. (Eds)

After the Damages Project Committees

HEADS
Marcello BALZANI, *University of Ferrara*
Riccardo DALLA NEGRA, *University of Ferrara*
Roberto DI GIULIO, *University of Ferrara*

SCIENTIFIC MANAGERS
Federica MAIETTI, *University of Ferrara*
Manlio MONTUORI, *University of Ferrara*
Fabiana RACO, *University of Ferrara*

DIDACTIC COORDINATION
Claudia PESCOSOLIDO, *University of Ferrara*

PROJECT PARTNERS
University of Ferrara
University of Parma
University of Modena e Reggio Emilia
Regione Emilia-Romagna, Agenzia Regionale per la Ricostruzione post sisma 2012
Soprintendenza Archeologia Belle Arti e Paesaggio per la città metropolitana di Bologna e le province di
Modena, Reggio Emilia e Ferrara
Istituto per i beni artistici culturali e naturali della Regione Emilia-Romagna

FACULTY MEMBERS
National University of Architecture and Construction of Armenia, Yerevan, Armenia
Faculdade de Arquitetura e Urbanismo, Departamento de Historia da Arquitetura e Estética do Projeto, Universidade de

Sao Paulo, Brazil Historia da Arquitetura e Estética do Projeto, Sao Paulo, Brazil
Escola da Cidade – Facultade de Urbanismo e Arquitectura di San Paolo, Brazil
Unversidade Presbiteriana Mackenzie, Facultade de Arquitectura e Urbanismo, San Paolo, Brazil
Burgundy School of Business, Université Bourgogne Research team in Arts and Cultural Management, Dijon, France
College of Civil Engineering (CCE), Fuzhou University, China
Universidad Politécnica Salesiana, Cuenca, Ecuador
University of the Faroe Islands, Faculty of Science and Technology, Torshavn, Faroe Islands
SAL School of Architecture, Gujarat Technoological University, Ahmedabad, India
Res-Arquitectura, Universitat Politècnica de València, València, Spain
Escuela Técnica Superior de Arquitectura, Granada, Spain
Özyegin University, Faculty of Architecture and Design, Istanbul, Turkey
Instituto do Patrimônio Histórico e Artístico Nacional – IPHAN, San Paolo, Brazil
Istituto de la Ciudad, Quito, Ecuador
Slovenian Association of Earthquake Engineering, Ljubljana, Slovenia
RehabiMed e Universitat Politècnica de Catalunya, Barcellona, Spain
Unione Italiana per il Disegno, Italy
Res-Arquitectura, Universitat Politècnica de València, València, Spain
Escuela Técnica Superior de Arquitectura, Granada, Spain
Özyegin University, Faculty of Architecture and Design, Istanbul, Turkey
Instituto do Patrimônio Histórico e Artístico Nacional – IPHAN, San Paolo, Brazil
Istituto de la Ciudad, Quito, Ecuador
Slovenian Association of Earthquake Engineering, Ljubljana, Slovenia
RehabiMed e Universitat Politècnica de Catalunya, Barcellona, Spain

TECHNICAL – SCIENTIFIC COMMITTEE
Cristina AMBROSINI, Soprintendenza Archeologia, Belle Arti e Paesaggio per la Città Metropolitana di Bologna e le Province di Modena, Reggio Emilia e Ferrara
Marcello BALZANI, University of Ferrara
Roberto BALZANI, Istituto per i beni artistici, culturali e naturali della Regione Emilia-Romagna
Alessandro CAPRA, University of Modena e Reggio Emilia
Cristina CASTAGNETTI, University of Modena e Reggio Emilia
Enrico COCCHI, Agenzia Regionale per la Ricostruzione – Sisma 2012 della Regione Emilia-Romagna
Eva COÏSSON, University of Parma
Riccardo DALLA NEGRA, University of Ferrara
Roberto DI GIULIO, University of Ferrara
Maria Luisa LADDAGO, Soprintendenza Archeologia, Belle Arti e Paesaggio per la Città Metropolitana di Bologna e le Province di Modena, Reggio Emilia e Ferrara
Antonino LIBRO, Agenzia Regionale per la Ricostruzione – Sisma 2012 della Regione Emilia-Romagna
Federica MAIETTI, University of Ferrara
Manlio MONTUORI, University of Ferrara
Fabiana RACO, University of Ferrara
Chiara VERNIZZI, University of Parma

SCIENTIFIC COMMITTEE
Imane BENNANI, Ecole d'Architecture de l'Université Internationale de Rabat, Marocco
Angelica ALVIM BENATTI, School of Architecture and Urbanism of Mackenzie Presbyterian University, San Paolo, Brasil
Stefano BERTOCCI, University of Florence, Italy
Patrizio BIANCHI, Big Data Technopole, Bologna, Italy
Elena BORIN, Burgundy School of Business, Université Bourgogne Franche Comté, France
Angelo BORRELLI, Dipartimento della Protezione Civile - Presidenza del Consiglio dei Ministri, Italy

Enza BOSETTI, Universidad Politécnica Salesiana, Cuenca, Ecuador
Bruno BRISEGHELLA, College of Civil Engineering, Fuzhou University, China
Marina BUNATYAN, National University of Architecture and Construction of Armenia, Yerevan, Armenia
Valter CALDANA, Universidade Presbiteriana Mackenzie, São Paulo, Brasil
Xavier CASANOVAS, RehabiMed e Universitat Politècnica de Catalunya, Barcellona, Spain
Carla DI FRANCESCO, Scuola dei Beni Culturali e del Turismo, Ministero dei Beni e delle Attività Culturali e del Turismo, Italy
Julio ECHEVERRIA, Universidad Central del Ecuador, Quito, Ecuador
François HARTOG, École des Hautes Études en Sciences Sociales EHESS, Parigi, France
Konstantinos KARANASOS, Ministry of Culture – The Acropolis Restoration Service, Greece
Beatriz Mugayar KÜHL, Faculdade del Arquitetura e Urbanismo, Universidade de Sao Paulo, Brasil
Marica MERCALLI, Direzione Generale Sicurezza del Patrimonio Culturale, Ministero dei Beni e delle Attività Culturali e del Turismo, Italy
Camilla MILETO, Universitat Politècnica de València, València, Spain
Cristiane MUNIZ, Escola da Cidade – Facultade de Urbanismo e Arquitectura di San Paolo, Brasil
Christian OST, School of Management, Bruxelles, Belgium
Harald PECHLANER, Università Cattolica di Eichstatt - Ingolstadt, Germany
Gethin WYN ROBERTS, University of the Faroe Islands, Denmark
Javier GALLEGO ROCA, Escuela Técnica Superior de Arquitectura, Granada, Spain
Rossella SALERNO, Polithecnic of Milan, Italy
Ronaldo RUIZ, Instituto do Patrimônio Histórico e Artístico Nacional - IPHAN, San Paolo, Brasil
Murat SAHIN, Özyegin University, Faculty of Architecture and Design, Istanbul, Turkey
Shrutie SHAH, SAL School of Architecture, Ahmedabad, India
Roko ZARNIC, Slovenian Association of Earthquake Engineering, Ljubljana, Slovenia

PARTICIPANTS
Lamiae AININE
Ruba Ahmad Hussien ALOMARY
Ilyes AMANI
Marco ANGELOSANTI
Isabella AZUL
Andrès BÄPPLER
Nelio Josè BATISTA COSTA
Rachele Angela BERNARDELLO
Tania Cristina BORDON MIOTO SILVA
Giulia BUFO
Olivia MALFATTI BUSCARIOLLI
Chiara CALLEGARO
Renata CAMPIOTTO
Cristina CIOVATI
Michele CORNIETI
Raffaella DE MARCO
Rossella DEL REGNO
João DUARTE
Leïla EL MOKHLIS
Ali DALALBASHI ESFAHANI
Marco FELLI
Haroldo GALLO
Raissa GAROZZO
Francesca GRAZIOSI

Emma HARUTYUNYAN
Alicia HUETO ESCOBAR
Janaina KROHLING PERUZZO
Gianfranco LAEZZA
Maria Irene LATTARULO
Andresa LEDO MARQUES
Paula CONSTANTINO CHAGAS LESSA
Bartolomeo LETIZIA
María LIDÓN DE MIGUEL
Eleonora MAGRINELLI
Ilaria MANETTA
Giorgio MATIS
Yvonne MAZUREK
Zineb MEGOUAR
Cecilia MENAPACE
Sanket MHATRE
Antonietta MILANO
Sara MORENA
Zeren ÖNSEL ATALA
Cilísia ORNELAS
Özge ÖZKUVANCI
Andrea PANZAVOLTA
Maurizio PERTICARINI
Nicolò PINI
Lucia PRATICÒ
Maria PREVITI
Flavio RIDOLFI
Giuseppe Camillo SANTANGELO
Alexandra SCUPIN
Jana SELIH
Chaitra SHARAD
Shad Sherzad JAWHAR
Chiara TOSTO
Francesca Maria UGLIOTTI
Isabel VALLE HERRERO
Mariana VAZ DE SOUZA
Emma ZIRALDO
Anna Vittoria ZULIANI

PATRONAGE
Consiglio Nazionale degli Architetti, Pianificatori, Paesaggisti e Conservatori, Italy
Green Building Council Italia
Clust-ER Build - Edilizia e Costruzioni, Emilia-Romagna, Italy
Istituto Italiano per il Disegno, Italy
ICOMOS Italia

Built Heritage in post-Disaster Scenarios – Balzani et al. (Eds)
© 2024 The Author(s), ISBN 978-1-032-18274-2
Open Access: www.taylorfrancis.com, CC BY-NC-ND 4.0 license

Analysis of damage mechanisms of fortified heritage and proactive information tools to prevent seismic risk

Elena Zanazzi*
Department of Engineering and Architecture, University of Parma, Parma, Italy

ABSTRACT: The recent Italian seismic events have highlighted the high seismic vulnerability of a very common and distinctive architectural type: fortified architectures. This research project, in partnership with Regional Agency for the Reconstruction –2012 Earthquake, focuses on the analysis of 21 castles damaged by 2012 Emilia earthquake.This article shows a first analysis of the large amount of data, produced after the seismic events of May 20th and 29th 2012, about the fortified architectures. The data are reorganized according to two levels: building level and territorial level. The first part of the article is focused on the analysis of typical damage mechanisms of fortresses, including the critical aspects of the application of the inventory sheet (form B-Palace) to the castle typology. The second part illustrates a GIS database, designed with a predictive approach. Indeed, this geodatabase is not only a passive storage system, but, uploading the shake-maps, it can become a tool for seismic risk prediction and damage prevention.

Keywords: Damage mechanisms, Emilia earthquake, fortified architecture, GI, proactive geodatabase

1 INTRODUCTION

In Italy, the experience of past earthquakes has highlighted not only the vulnerability of architectural heritage, but also the critical aspects of tools for the prediction of their seismic behavior. Indeed, the standard modeling procedures for ordinary buildings cannot be used for complex masonry structures, which characterized the majority of Italian historical heritage, such as churches, palaces and last but not least fortified architectures. This article focuses on the analysis of 21 Emilian castles damaged by the seismic events of May 20th and 29th, 2012 (Figure 1). In order to forecast the real vulnerabilities of this typology, it is necessary to take a step back and adopt an empirical approach, linked to the observation of damage. Indeed, it has been widely recognized that each masonry building typology is associated with specific recurrent damages (Blasi, 2013). However, there are typologies that are more studied than others.

The 1976 Friuli earthquake, for example, provided the occasion for the first systematic study of the effects of a seismic event on specific masonry structures, such as churches (Doglioni et al., 1994). Then these studies were implemented by the *Linee Guida* (Guidelines, 2008), which include specific inventory sheets for churches (form A) and palaces (form B), with the abacuses of damage mechanisms. The inventory sheets divide churches and palaces into specific macro- elements and associate each of these to one or more damage mechanisms.

Therefore, the 2012 Emilia earthquake can become an opportunity to study the mechanism of other historical masonry structures, which are vulnerable to the earthquakes. In this regard, in 2018, a program of Emilia Romagna Region has funded three PhD researches, in collaboration with the *Agenzia Regionale per la Ricostruzione – Sisma 2012* (Regional Agency for the Reconstruction – 2012 Earthquake), for the analysis of three architectural types, until today

*Corresponding author: elena.zanazzi@unipr.it

DOI: 10.1201/9781003253730-17

great absents in the Italian technical laws, although they are widely spread: theaters, cemeteries and fortified architectures. These typologies get damaged by typical and recurring mechanisms. It would be necessary to define a specific tool for the damage survey of these typologies.

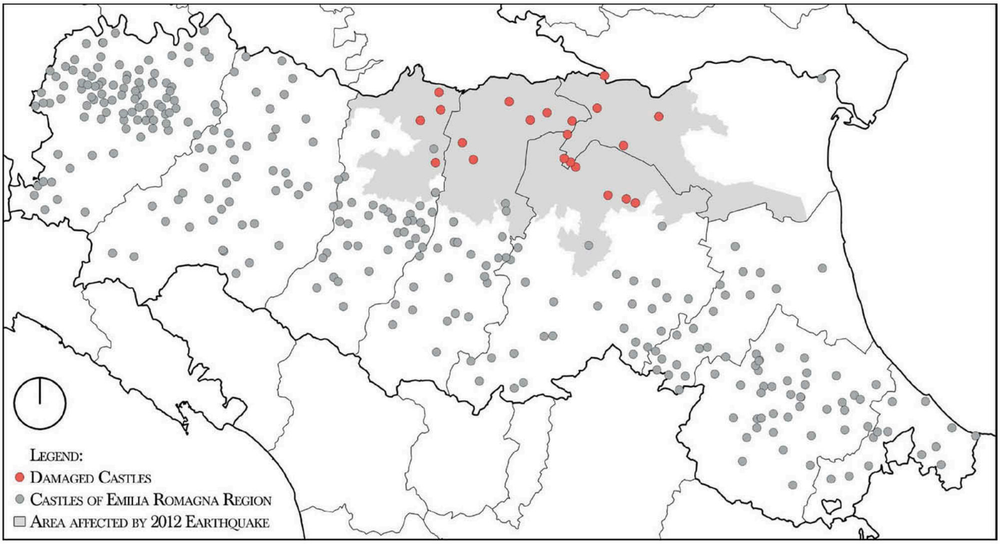

Figure 1. Localization of Emilia Romagna fortresses (in gray) and of the 21 damaged case studies (in red).

The fortresses, widely spread in Emilia Romagna Region, were affected, and extensively damaged, by the earthquake of 2012 and by the more modest of 2008. These events, especially the most recent, have prompted analysis of the effects of the earthquake on such historical structures, for example Cattari et al. (2014) and Coïsson et al. (2016), where it is pointed out that today, unfortunately, there is not an Italian national list of these assets and their state of conservation. Furthermore, in this regard it would be very useful to design proactive software to identify the vulnerability of architectural heritage on a territorial scale (Lenticchia et al., 2017). In compliance with the tools currently used by the government of Emilia Romagna Region, this research project takes advantages of the use of GIS (Geographic Information System), in order to highlight the main vulnerabilities and weaknesses of each building analyzed and to prevent the seismic risk.

2 THE HISTORICAL EVOLUTION OF THE FORTIFIED ARCHITECTURES IN EMILIA: CONSTRUCTIVE FEATURES AND VULNERABILITIES

The Emilia Romagna Region is characterized by the presence of more than 300 fortified architectures on its territory (Web-1). Indeed, the division and the political instability of the Emilia Romagna Region, which lasted until the end of the 15th century, had contributed to the wide spread of fortresses (Perogalli, 1972). The term fortified architecture actually includes a very wide variety of buildings, such as castles, fortresses, citadels, fortified villages and other constructions (Perogalli et al., 1979; Cassi Ramelli, 1964; Caciagli, 1979). This research project focuses on the analysis of 21 fortified architectures damaged by the 2012 earthquake (Figure 1). The case studies were selected thanks to the results of the queries of the WebGis of the Emilia Romagna Region (Web-1) and in order to identify a homogeneous set of case studies, with common and comparable characteristics:

2.1 *The materials*

The above fortified architectures, built or renovated under the impulse of an imminent danger, are characterized by the use of local materials, cheap and easy to find (Aceto, 1995; Tosco, 2003). Therefore, in Po valley the masonries are mostly made of bricks and lime mortar (Balestracci, 1989; Mantovani, 2003). After the analysis of the documentation deposited in the archives of the *Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Bologna e le province di Modena, Ferrara e Reggio Emilia* (Cultural Heritage Department for the metropolitan city of Bologna and the provinces of Modena, Ferrara and Reggio Emilia), it emerges that these structures have usually a core walls made of reused bricks and poor lime mortar. For this reason, the leaves are not well connected and often they are completely independent. This circumstance represents a first condition of seismic vulnerability of the fortresses and it is the main cause of the delamination of the cladding.

2.2 *The historical period*

These case studies are included in a temporal range from the 11th century to the 15th century, in this historical period it is possible to include the historical parabola of Emilian fortified architecture (Perogalli, 1972), except in cases of massive restorations between the 19th and 20th centuries, due to gothic revival.

2.3 *The plan*

During the 14th century the plans of the castles in Emilia, especially those located in the Po valley, take a more defined and regular geometric shapes, usually square or rectangular, with square towers at corners and an inner courtyard, accessible through an entrance tower. However, the regular plan will only become the rule in the second half of the 15th century (Perogalli, 1972).

2.4 *Typical elements*

In a fortified complex, it is possible to easily distinguish primary characterizing elements (tower, curtain wall, *palatium*) and secondary ones (merlons, corbels, and other protruding elements). Each element corresponds to one or more damage mechanisms. However, these elements are the result of subsequent changes and improvements, due to a close dialogue between defense and offense, where the first follows and has to constantly adapt to the technological evolution of the second, in order to avoid the inadequacy of the fortress and its subsequent neglect (Cassi Ramelli, 1964). This stratification of different non-coeval structures, within the fortified complex, has certainly represented a second condition of seismic vulnerability. In detail, the two essential elements of the fortifications, until the 10th century, are: the curtain walls, the first ancestral defense, which consists essentially of a continuous fence, and the tower, with the function of sighting. Later the towers began to be built adherent to the walls and the space inside the walls was populated, in a spontaneous and unorganized way, by permanent buildings. The fortified architectures, characterized by a single compact building, are generally of 13th century and especially of 14th century. The Emilian castles of the late Middle Ages (in the late 13th and in the late 14th century) are of three main types: the castle in height (not common), the castle with a central tower, like the fortress of Reggiolo, and the one with angular towers, for example the Castle of Ferrara (Perogalli, 1972). In the provinces of Parma and Modena, in the first half of the 15th century, these buildings began to be equipped with protruding elements, such as corbels, for the pouncing defense. In the second half of the 15th century, the invention of artillery led to a thickening of the walls, in order to absorb the shots. However, at the end of 15th century, the development of warfare techniques will make the Emilian fortifications obsolete. Therefore, the castles take on a residential function, and, in several cases, are transformed into villas (Perogalli, 1972).

This diachronic evolution is one of the causes of poorly connection of the structures, and this condition has generated disastrous phenomena of hammering (tower-curtain wall), or of the presence of buildings adherent to pre-existing structures, for example this condition has caused widespread phenomena of slipping of the beams of the floors of the palatium adherent to curtain walls. Moreover,the considerable differences in height, between the towers and the other buildings, and the position of the towers (at corner, incorporated, protruding or isolated) are certainly elements of further vulnerability.

3 LEARN FROM THE 2012 EMILIA EARTHQUAKE

3.1 *Damage inventory sheets*

In the post-earthquake emergency, the surveys of listed properties, in the areas affected by the earthquake, were immediately started. In Italy, the census of the damages on the listed assets currently uses only two inventory sheets for two specific architectural types: form A, for the churches, and form B, for the Palaces (Papa et al., 2011). These damage inventory sheets are the result of a continuous evolution and integration, after every earthquake. In particular, the form A comes from the studies of Doglioni (1994), carried out through direct observation of the damages of the 1976 Friuli earthquake on churches. In 2001, the form A included only 18 damage mechanisms, increased to 28 in 2006. After theon-the-ground implementation of the inventory sheets form A, it appeared that it was necessary to integrate the damage survey tools with another specific form for palaces. Thus, the inventory sheet form B was born. Then it was applied, for example, in the 2002 Molise earthquake.

3.2 *Damage inventory sheets: Weaknesses*

However for the prompt survey of damages to listed assets, which do not belong to the two aforementioned architectural typologies, the forms A or B are still applied. After the 2012 seismic events, the form B – Palaces were used for the census of damages of fortified architectures. Therefore, the first critical aspects arise. Indeed, if some damage mechanisms of fortified buildings are similar to the mechanisms of the abacus of the inventory sheet B - Palaces, it is also true that fortified architectures are characterized by further typical elements (massive towers, curtain walls, battlements, corbels, walls…), whose seismic behaviors are not in the existing inventory sheets. In this regard, the analysis of the inventory sheets, drawn up in 2012, shows that, on several occasions, the surveyor has used the voice "other" to describe the mechanisms absent in the inventory sheet, but typical and recurrent in the castles: overturning of the battlements and torsion of the towers (Figure 2). Moreover, in several cases, in the same inventory sheet, the damage to the merlons has been recorded simultaneously in two different sections: B19 (damage to structural elements) and B20 (damage to non-structural elements). In some cases there are also transcription errors and forgetfulness. For this reason it is hoped that, in the future, these tools will be digitized, in order to guide the surveyor in the compilation and to speed up the procedure.

	CASE STUDIES	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23
Bologna	Fortress of Pieve di Cento						3																	
	Galeazza Pepoli Castle	5		4			5	5			5	5	2	4	5		5	4	5	4	4			5
	Manzoli Castle	3						2	1		2		2		4				3		2			
	Bentivoglio Castle	2					1	2			2	1							2					
	Fortress of Minerbio			3			2	2			2		2	1	1					2				
	La Giovannina Castle				4	4	3	3		2			3		3					2	2			4
Ferrara	Castle of Ferrara	3			5	3	2	2	4		2		2	1	3	5	2		4					
	Lambertini Castle			3		3	3	4		2		3			3	2			5				1	
	Fortress in Stellata of Bondeno	3										4	4	4	3		3	3	3					
	Fortress of Cento	2				4											2							
	Castle in Santa Bianca of Bondeno					4		4			2					1	1				2			
Modena	Fortress of S. Felice sul Panaro	4			5	3	2	3	4		3	5	4			5	5	5	1		3	2		
	Campori Castle in Soliera					4		2		1					3		2		4		2	2		4
	Pico Castle in Mirandola	4	4		4	4	3	3		4	4	5	3		3		4	4		5	4			
	Pio Castle in Carpi	2				3	3	4		2	2	2		3	3	3	3		2	3	2	4		
	Fortress of Finale Emilia		1		3	2	2	1		4				3			4				1			5
	Carrobbio Castle in Massa Finalese			2			2	2		3		4			4	3	3				4		3	4
Reggio Emilia	Fortress of Reggiolo	3				4	4			5	5				4	5	5							5
	Castle of S. Martino					1	1	1			1		2	2	2		2		1	2	2	2	1	
	Guidotti Castle in Fabbrico						1	1		2	3			2	2									
	Gonzaga Fortress in Novellara					1		1						1	1									1

Legend of damage mechanisms:
M1 overturnig of the walls
M2 vertical flexural mechanisms,
M3 horizontal flexural mechanisms,
M4 overturning of the corner,
M5 shear cracks of façade (bearing wall),
M6 shear cracks of façade (lintel),
M7 shear cracks of internal walls,
M8 sliding of floor,
M9 damage to loggias and porches,
M10 slippage of the beam from the supports,
M11 local collapse of the floors,
M12 damage to the vault due to movements of the supporting elements,
M13 damage to the vault due to strain strength,
M14 damage to stairs,
M15 damage to roof frame,
M16 damage to roofing shingles,
M17 overturning of wall in the garret area and of gable wall,
M18 damage of protruding elements,
M19 local collapse due to construction irregularities,
M20 damage due to irregural shape,
M21 added buildings,
M22 foundation settlement, M23 other.

Figure 2. Damage levels from the inventory sheets form B draw up in 2012.

3.3 *Typical damage mechanisms of fortified architectures*

Therefore, starting from the analysis of the literature (Cattari et al., 2014; Coïsson et al., 2016, 2017; Ferretti et al., 2018) and from the observation of real damages of Emilian castles, through reports and photographic documentation, found at the above mentioned Soprintendenza, it was possible to census, in an organized way, the recurrent damage mechanisms for the typical elements of the Emilian fortified architecture, defining for each mechanism a damage level scale from 0, no damage, to 5, collapse. An overview of some of the most significant mechanisms is shown in Figure 3.

In view of these considerations, it seems therefore useful to implement the tools available today. In particular, one of the aims of this research project is to define a possible proposal for a specific damage inventory sheet for fortified architecture.

4 A PROACTIVE GEODATABASE FOR EMILIAN FORTRESSES

Essential key to the elaboration of this study is the use of GIS (Geographic Information System), which is not only a passive storage system of large amounts of data, but also a proactive tool to define the vulnerabilities on a territorial scale and to forecast and prevent seismic risk. In particular, ArcGIS Pro, a ESRI software, is the software in use. The geographic reference system used fot the geodatabase designed is WGS84 UTM32. In order to transform the experience of the 2012 earthquake on cultural heritage into an opportunity for prevention, it is necessary to start from the analysis of the large amount of documents produced after the 2012 seismic events. Indeed, the study started analyzing the digital data, provided by the Segretariato Regionale (Regional Secretariat), in shapefile format. The attribute tables of these shapefiles and the related physical models were implemented with further information obtained from the inventory sheets, but mainly from the documentation deposited in the archives of the aforementioned Soprintendenza. Indeed, as it is easy to imagine, the stored documentation is more detailed and it should not incur in errors and forgetfulness, typical of

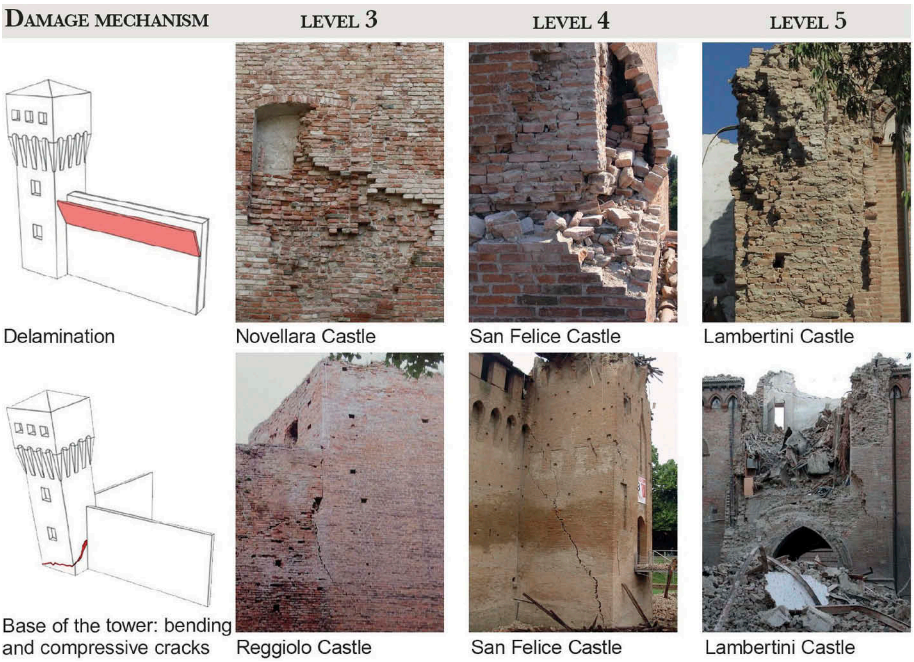

Figure 3a. Some of most significant damage mechanisms (Lenticchia et al., 2017) and the photos of the three most severe damage levels.

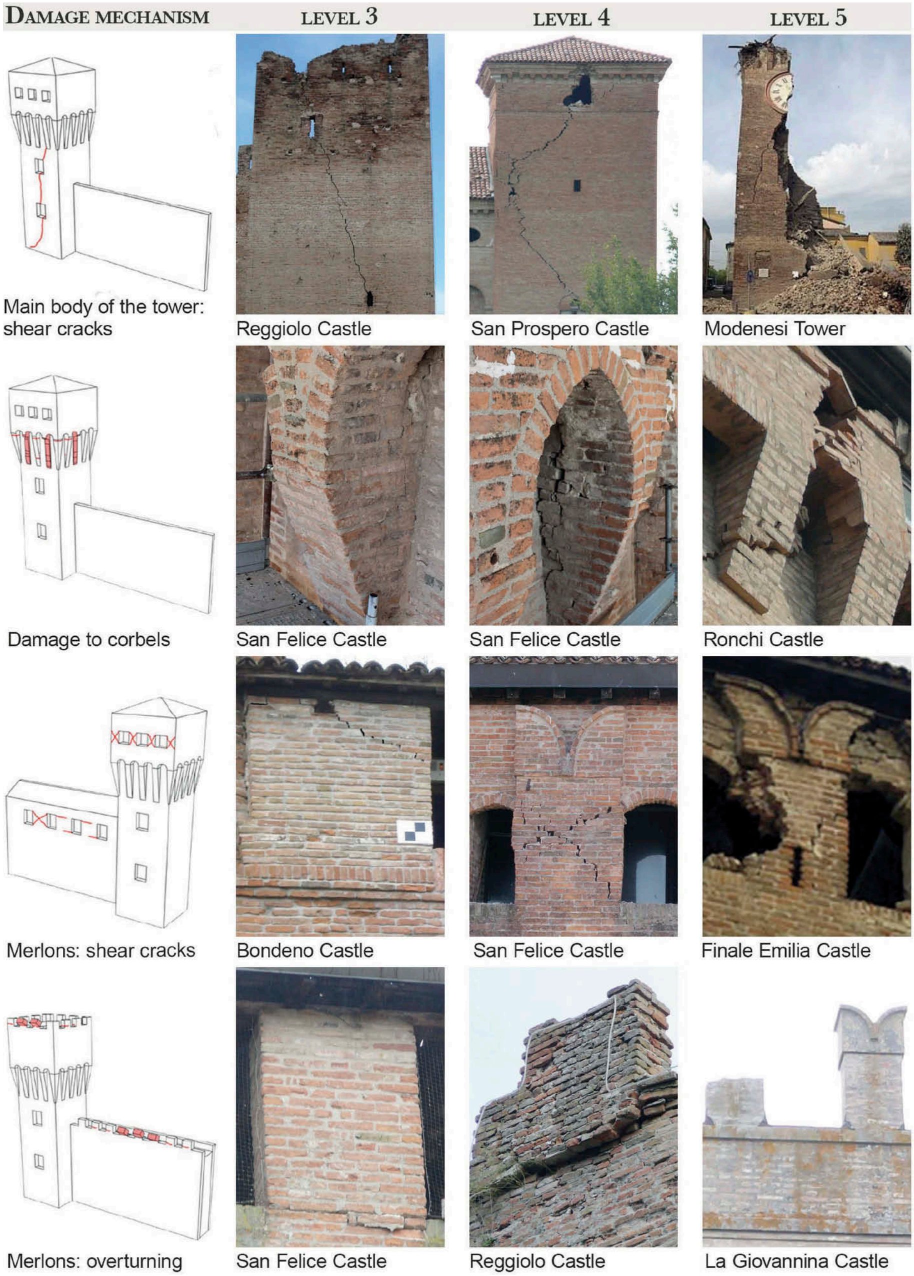

Figure 3b. Continued.

the prompt survey. However, as mentioned above, the project of this database is not only aimed at the systematic and organized storage of the data found. Indeed, a GIS database, being a query software, gives also the possibility to easily compare data of any kind (numerical or textual), even from a predictive point of view. For example, from the preliminary analysis of the data it emerges that free-standing merlons tend to overturning out of plane more frequently than merlons supporting a roof, while the latter tend to be damaged by shear cracks. This example shows that it is possible to identify in advance the main vulnerabilities of the listed assets and potentially prevent and avoid the damages. Moreover, in a second phase, shakemaps have been uploaded in the geodatabase. Shakemaps are a graphic representation of the soil motion (in terms of acceleration, velocity, or displacement). Shakemaps are created in real time by INGV, downloadable as shapefile from INGV web site (Web-3), and finally easily uploaded in the GIS. Thus, for each damaged castle, it has been possible to associate the damage levels to each mechanisms described above and to compare them with the maximum values of PGA, PGV, PSA, suffered during the 2012 seismic swarm (Figure 4), in order to understand which of the three values has a better correlation with each damage mechanism. In particular, 9 shakemaps of the events, with magnitude IM ≥ 5, have been overlapped thanks to the GIS software, in order to find the maximum values. Finally, this phase of analysis and data collection will be fundamental for the elaboration of vulnerability curves for each mechanism, useful to prevent the seismic damages.

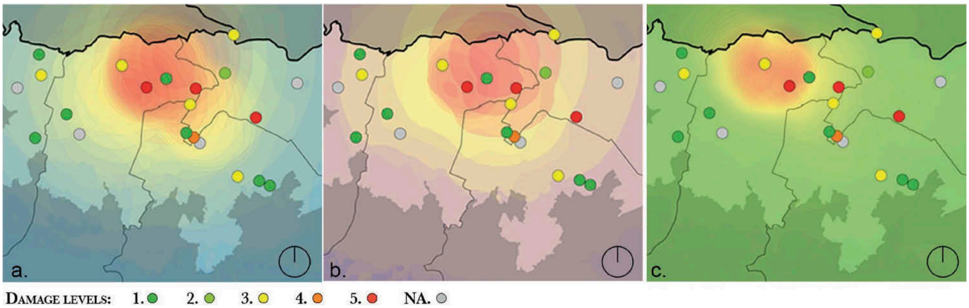

Figure 4. By way of illustration, the figure shows the damage levels for the mechanism of "shear craks" of merlons, with the shakemaps in terms of a. PSA, b. PGA, c. PGV.

5 CONCLUSIONS

Fortified architectures are a very widespread architectural typology in Emilia Romagna and in the whole national territory. This article has focused on the analysis on seismic damages of fortified architectures in Emilia Romagna, which have proved to be highly vulnerable to earthquakes, due to some of their typical characteristics: diachronic evolution of the buildings, not well-connected structures, constructive and geometric features. Thus, because of their recurrent vulnerabilities and, at the same time, because they are so widespread, it is necessary to define an ad hoc damage inventory sheet for fortified architectures. In this way, it will be possible to facilitate the prompt survey, without losing precious information in this first emergency phase.

However, at the same time, it is necessary today, in peacetime, to work to define tools that forecast the vulnerabilities of protected assets on a territorial scale. This type of analysis at a territorial scale takes large advantage of the use of GIS and could be replicated also for other seismic events; in order to act before the expected damage happens. In this regard, the designed geodatabase can be considered a predictive tool for the analysis and forecast of the seismic risk of the architectural heritage. Indeed, thanks to seismic hazard maps, uploaded in GIS software, it is possible to identify the structural elements which are mostly in danger, known their expected seismic action. In addition, it would be possible to do a list of the most urgent interventions and to plan a preventive maintenance program, avoiding operating always in an emergency phase.

ACKNOWLEDGEMENTS

I would like to thank the Agenzia Regionale per la Ricostruzione – Sisma 2012 (Regional Agency for the Reconstruction – 2012 Earthquake), in particular Architect Antonino Libro and Engineer Davide Parisi, for the numerous and valuable suggestions; Dr. Silvana Parisi for the help provided during the consultation of the material stored at the Archives of the Superintendence and finally Professor Eva Coïsson and Professor Daniele Ferretti for the supervision of my ongoing thesis project.

REFERENCES

Balestracci Duccio. 1989. I materiali da costruzione nel castello medievale. Archeologia Medievale 16. Accessed June 9, 2021. https://www.proquest.com/scholarly-journals/i-materiali-da-costruzione-nel-castello-medievale/docview/1298011460/se-2?accountid=16740.

Blasi Carlo (eds.). 2013. *Architettura storica e terremoti. Protocolli operativi per la conoscenza e la tutela*. Milan: Wolters Kluwer.

Caciagli Giuseppe. 1979. *Il castello in Italia*. Florence: Giorgi & Gambi. Cassanelli Roberto (eds.). 1995. *Cantieri Medievali*. Milan: Jaca Book.

Cassi Ramelli Antonio. 1964. *Dalle caverne ai rifugi blindati*. Milan: Nuova Accademia Editrice.

Cattari Serena, Degli Abbati Stefania, Ferretti Daniele, Lagomarsino Sergio, Ottonelli Darla and Tralli Antonio. (2014). Damage assessment of fortresses after the 2012 Emilia earthquake (Italy). Bulletin of earthquake engineering 12(5): 2333–2365.

Coïsson Eva, Ferretti Daniele and Lenticchia Erica. 2017. Analysis of damage mechanisms suffered by Italian fortified buildings hit by earthquakes in the last 40 years. Bulletin of Earthquake Engineering 15(12): 5139–5166.

Coïsson Eva, Ferretti Daniele and Lenticchia Erica. 2016. Italian castles and earthquakes: A GIS for knowledge and preservation. Structural Analysis of Historical Constructions: Anamnesis, Diagnosis, Therapy (12–16 September 12–16, 2016). Leuven: CRC Press/Balkema.

Doglioni Francesco, Moretti Alberto and Petrini Vincenzo. 1994. *Le chiese e il terremoto - Dalla vulnerabilità constatata nel terremoto del Friuli al miglioramento antisismico nel restauro, verso una politica di prevenzione*. Trieste: Ed. LINT.

Ferretti Daniele, Coïsson Eva and Lenticchia Erica. 2018. Seismic damage on merlons in masonry fortified buildings: A parametric analysis for overturning mechanism. Engineering Structures 177: 117–132.

Guidelines, 2008. *Guidelines for evaluation and mitigation of seismic risk to cultural heritage*. Rome: Gangemi

Lenticchia Erica and Coïsson Eva. 2017. The use of gis for the application of the phenomenological approach to the seismic risk analysis: the case of the italian fortified architecture. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 42.

Mantovani Sergio. 2003. Fortificazioni estensi nella pianura tra Modena e Bologna all'epoca del duca Ercole I. In Bonacini Pierpaolo, Cerami Domenico (eds.). Rocche e castelli lungo il confine tra Bologna e Modena. Atti della Giornata di Studio (25 October 25, 2003). Vignola: Fondazione Vignola

Papa Simona and Di Pasquale Giacomo (eds.). 2011. *Manuale per la compilazione della scheda per il rilievo del danno ai beni culturali, Chiese MODELLO A – DC*. Accessed June 9, 2021. http://www.awn.it/component/attachments/download/1247

Perogalli Carlo. 1972. *Castelli e Rocche in Emilia Romagna*. Milan: Gorlich Editore

Perogalli Carlo, Ichino M. Paola and Bazzi Silvana. 1979. Castelli italiani: con un repertorio di oltre 4000 architetture fortificate. Monza: Bibliografica

Tosco Carlo. 2003. Il castello, la casa, la chiesa. Architettura e società nel Medioevo. Turin: Einaudi

WEB SITES

Web-1: https://www.patrimonioculturale-er.it/webgis/, consulted May 28, 2021
Web-2: https://www.istat.it/it/archivio/222527, consulted May 31, 2021
Web-3: http://shakemap.ingv.it/shake/, consulted May 31, 2021