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University of Pisa

DIPARTIMENTO
INGEGNERIA
dell'Energia, dei Sistemi, del Territorio e delle Costruzioni

UNIVERSITÀ DI PISA

SEISMIC RISK MANAGEMENT IN HISTORIC CENTRES.
Integrated large-scale modelling for a scenario-based methodology

PhD candidate Francesca Giuliani

Supervisors dr. eng. Anna De Falco
prof. eng. Valerio Cutini

OUTLINE

- **INTRODUCTORY OVERVIEW OF THE PROBLEM:**
  Problem definition
  Research objectives and design

- **STATE OF THE ART:**
  Risk assessment, risk management and earthquakes
  Large-scale vulnerability assessment: from the built environment to the road network
  Spatial analysis

- **METHODOLOGY:**
  Screening phase: territorial-level investigations
  Development phase: local-level investigations

- **RESULTS AND DISCUSSION**
  Territorial-level investigations : 9 historic centres
  Local-level investigastions: 1 historic centre

- **CONCLUSION AND FUTURE DEVELOPMENTS**

INTRODUCTION

Problem definition

1908 Reggio Calabria and Messina	1915 Marsica	1968 Belice	1976 Friuli	1980 Irpinia	1997 Umbria e Marche	2002 Molise	2009 Abruzzo	2012 Emilia Romagna	2016 Central Italy

RISK ASSESSMENT

R=f(Hazard**, V**ulnerability**, E**xposure**)**

MAIN CHALLENGES

- Historic centres present high vulnerability and high exposure
- Vulnerability assessment hindered by the «aggregate effect» and the lack of detailed large-scale knowledge on historical buildings
- Lack of data regarding the real exposure (population, visitors, tourists, and value of cultural assets)
- Not possible to intervene on the whole historic centre, namely the built environment and the road network
- Lack of coordination between experts and disciplines

METHODOLOGY

Objectives and research methodology

TO PROPOSE AN INTEGRATED METHODOLOGY FOR THE DEVELOPMENT OF A SEISMIC RISK MANAGEMENT PLAN IN ITALIAN HISTORIC CENTRES

Key principles:

1. **BALANCE PRESERVATION AND SAFETY THROUGH PREVENTION**
2. **PLAN INTERVENTIONS AND PRIORITIZE PREVENTION MEASURES**
3. **STRENGTHEN THE CONNECTION BETWEEN EMERGENCY AND PREVENTION**
4. **INCLUDE THE PROCESS OF HUMAN EVACUATION INTO THE EMERGENCY PLANNING**

SCREENING PHASE: territorial–level investigations

Objective: identify synthetic measures to compare historic centres in terms of **system vulnerability**

▶

DEVELOPMENT PHASE: local–level investigations

Objective: develop a general methodology for the development of DRM plans for historic centres

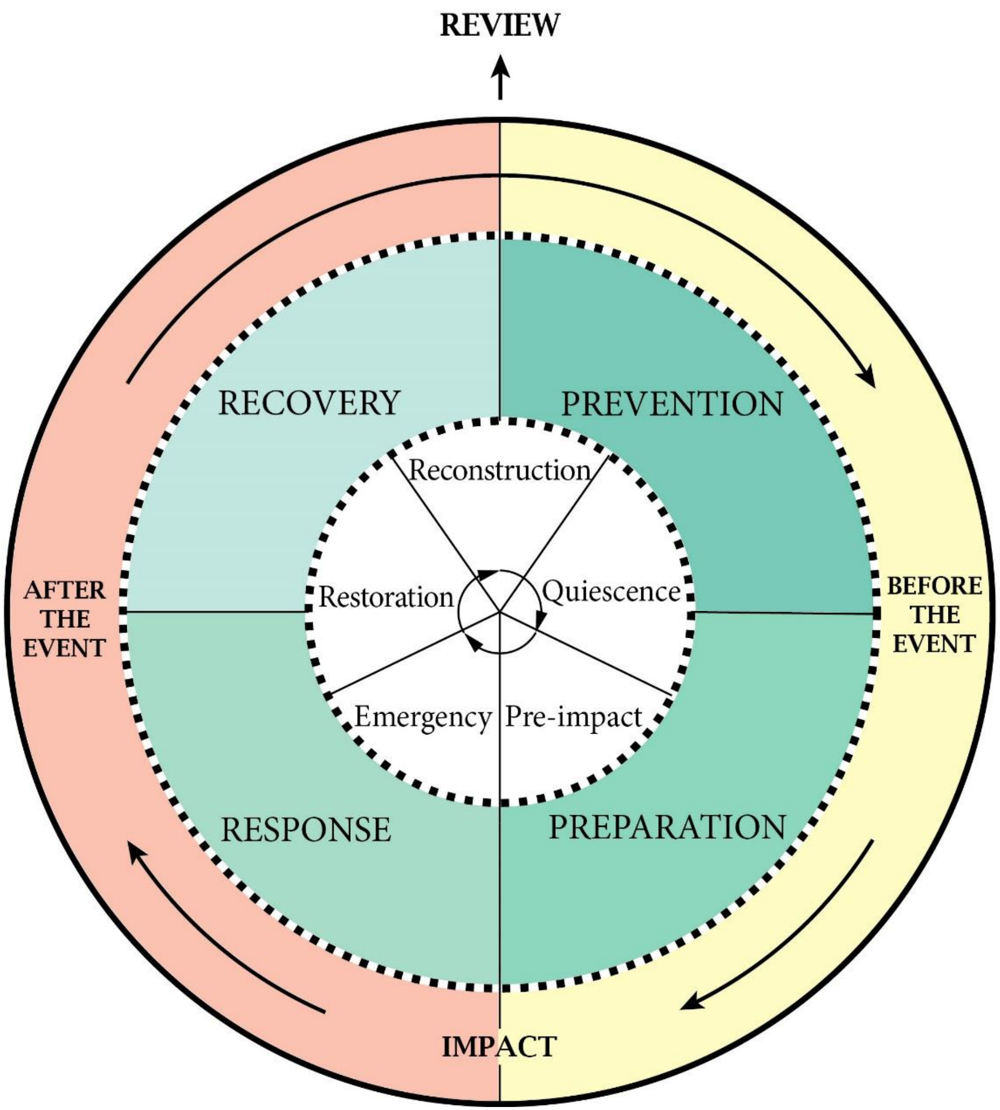
Risk assessment, risk management and earthquakes

RISK ASSESSMENT
R=f(Hazard**, V**ulnerability**, E**xposure**)**

RISK MANAGEMENT
4 phases

SEISMIC RISK MANAGEMENT IN ITALY
National Seismic Prevention Programme

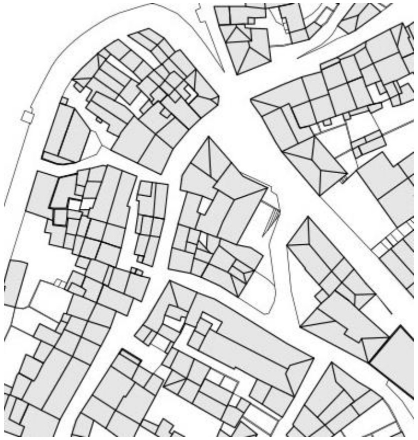
- ✓ Improvement of the technical-scientific **knowledge** (seismology, earthquake engineering, any earthquake-related subject);
- ✗ Reduction of the **vulnerability** and **exposure** (no intervention on seismic hazard) during **prevention**;
- ✓ Mitigation of the effects (**preparation** and **response** phases), namely all the efforts to foster the culture of civil protection and rise awareness on risks.



Disaster Risk Management Cycle (DRMC)

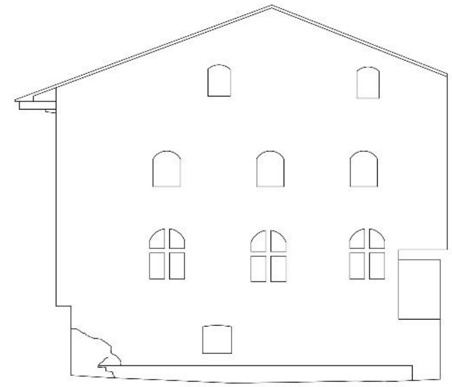
STATE OF THE ART

Large-scale vulnerability: from the built environment to the road network



URBAN SCALE

AGGREGATE SCALE



BUILDING SCALE

Less detailed knowledge

Decrising complexity

Increasing uncertainty

Decreising evaluation time per case

EMPIRICAL

Damage Probability Matrices (DPM)
•
vulnerability curves
•
Vulnerability Index Methods (VIM)
•
screening methods

ANALYTICAL (NUMERICAL AND MECHANICS)

Finite Elements Method (FEM)
•
Simplified Elements Method (SEM)
•
Discrete Elements Methods (DEM)

More detailed knowledge

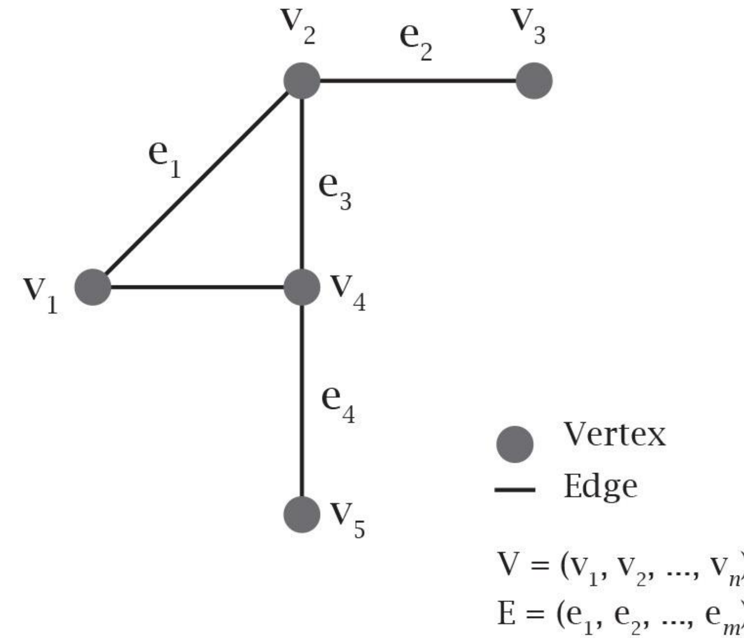
Increasing complexity

Decreasing uncertainty

Increasing evaluation time per case

Spatial analysis

- It is a set of techniques for **representation, quantification** and **interpretation** of **spatial configuration**
- Mutated from the Network Analysis and the Graph Theory



DEGREE CENTRALITY

$$C_D(v) = \deg(v)$$

$$|C_D(n)| = \frac{\sum_{i=1}^{n}[C_D(v^*) - C_D(v_i)]}{max \sum_{i=1}^{n}[C_D(v^*) - C_D(v_i)]}$$

CLOSENESS CENTRALITY

$$d_{i,j} = \text{distance between } v_i \text{ e } v_J, i \neq j$$

$$C_C(j) = \frac{1}{\sum_j d_{i,j}} \qquad |C_C(j)| = \frac{N-1}{\sum_j d_{i,j}}$$

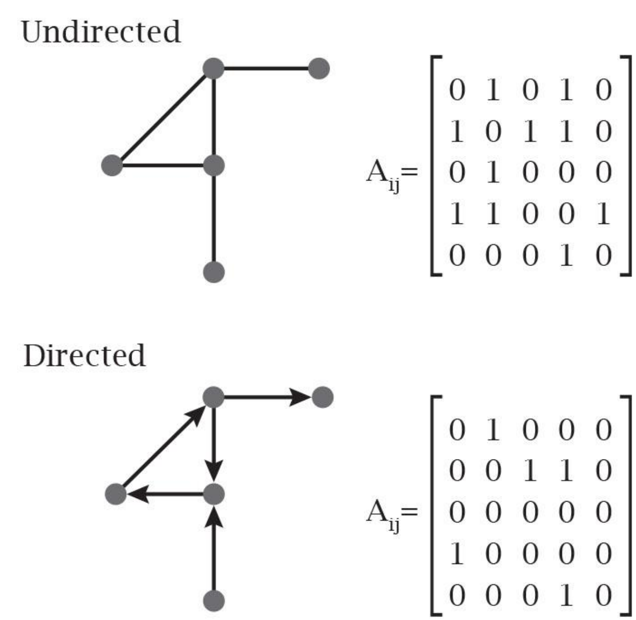
BETWEENNESS CENTRALITY

$$\sigma_{i,j} = \text{number of geodesics tra } v_i \text{ e } v_J, i \neq j$$

$$C_B(k) = \sum_{i<j} \frac{\sigma_{i,j}(k)}{\sigma_{i,j}} \qquad |C_B(k)| = \frac{\sum_{i<j} \frac{\sigma_{i,j}(k)}{\sigma_{i,j}}}{H}$$

$$H_{directed} = (n-1)(n-2)$$

$$H_{undirected} = \frac{(n-1)(n-2)}{2}$$

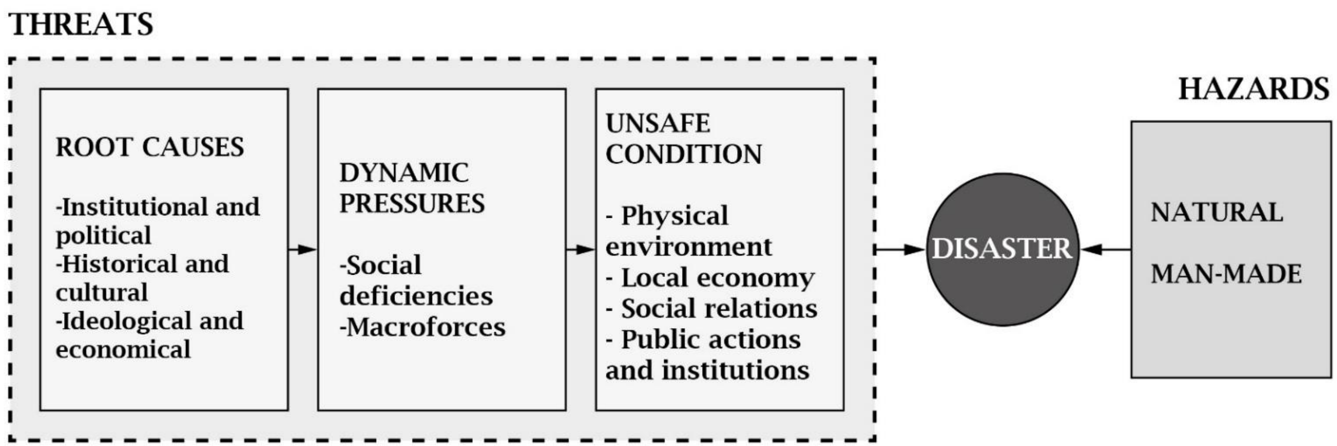


TERRITORIAL-LEVEL: METHODOLOGY

Screening phase: analysis, comparison and synthesis

a. URBAN VULNERABILITY

Object: historical system
Method: Pressure And Release (PAR) model



b. URBAN MORPHOLOGY

Object: built environment
Method: Process typological analysis

- Settlement > block > district
- **Compactness: SI**
- **Size: A_{HC}**

c. URBAN CONFIGURATION

Object: open spaces
Method: spatial analysis

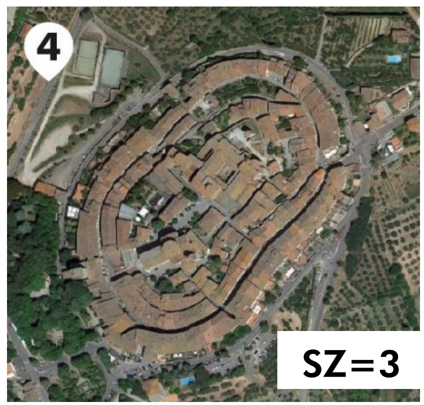
- Angular Segment Analysis
- **Connectivity (degree centrality)**
- **Choice (betweenness centrality)**
- **Integration (closeness centrality)**
- **Redundancy: $\bar{C}$**
- **Distribution: v**

depthmapX

TERRITORIAL-LEVEL: RESULTS

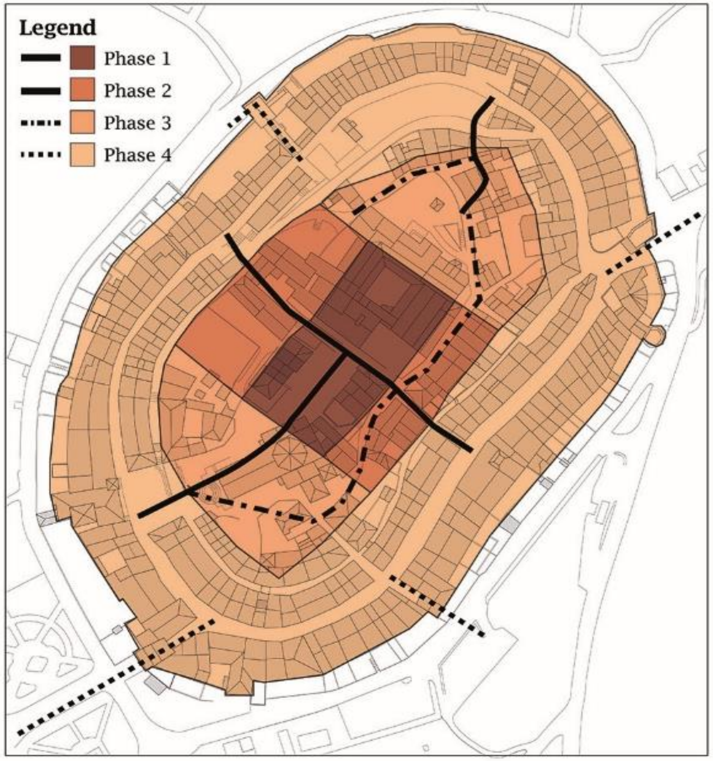
Case studies: 9 historic centres

1. Certaldo
2. Chianni
3. Lari
4. Lucignano
5. Pontremoli
6. Poppi
7. San Gimignano
8. Vinci
9. Volterra



Sample results

ID	Historic centre	Territorial location	Nucleus type
1	Certaldo	low hill	village
2	Chianni	high hill	village
3	Casciana Terme Lari	low hill	village
4	Lucignano	high hill	proto-urban
5	Pontremoli	high valley	urban
6	Poppi	high hill	proto-urban
7	San Gimignano	high hill	urban
8	Vinci	low hill	proto-urban
9	Volterra	high hill	urban

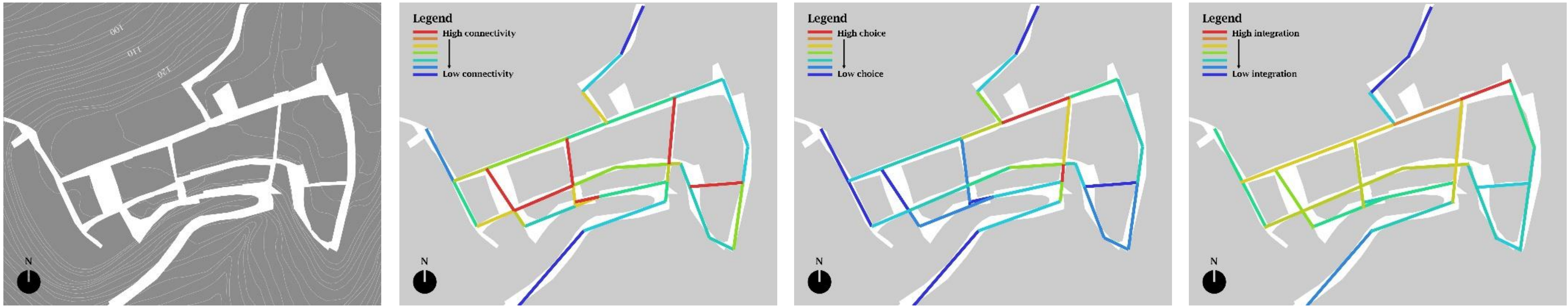


CERTALDO

Connectivity

Choice

Integration



TERRITORIAL-LEVEL: CONCLUSIONS

OVERALL CONCLUSIONS

- Great variety in the characteristics of historic centres
- Comparative measures of historic centres: compactness, size, redundancy, distribution

QUALITATIVE URBAN VULNERABILITY

- Set of mitigation measures > starting point for local-level strategic planning

URBAN MORPHOLOGY

- Identify the most ancient areas > address local-level surveys

SPATIAL ANALYSIS

- Identify centralities
- Common features:
  - higher connectivity next to gateways in walled cities
  - integration and choice are higher next to public or religious buildings
  - no correspondence between emergency land uses and centralities

LOCAL-LEVEL: METHODOLOGY

Development phase

OBJECTIVES

- Interdisciplinary methodology to develop DRM plans for historic centres
- Combination of **functional**, **vulnerability** and **spatial analyses** > **scenarios**

STEPS

1. **Extensive data collection and intensive survey**
   Methods and tools:
   a. Survey form (fieldwork)
   b. GIS mapping (pre- and post-fieldwork)
   c. Photogrammetry (fieldwork and post-fieldwork)
1. **Elaboration of data and definition of the database**
   Methods and tools:
   a. Database architecture
   b. GIS mapping
2. **Analytical investigations**
   Methods:
   a. LCE
   b. Vulnerability Index Method for masonry façades
   c. Spatial analysis, Angular Segment Analysis
3. **Definition and analysis of scenarios (emergency, damage and accessibility)**
4. **Combination of scenarios**

QGIS

PhotoScan
3D Modeling and Mapping
Agisoft

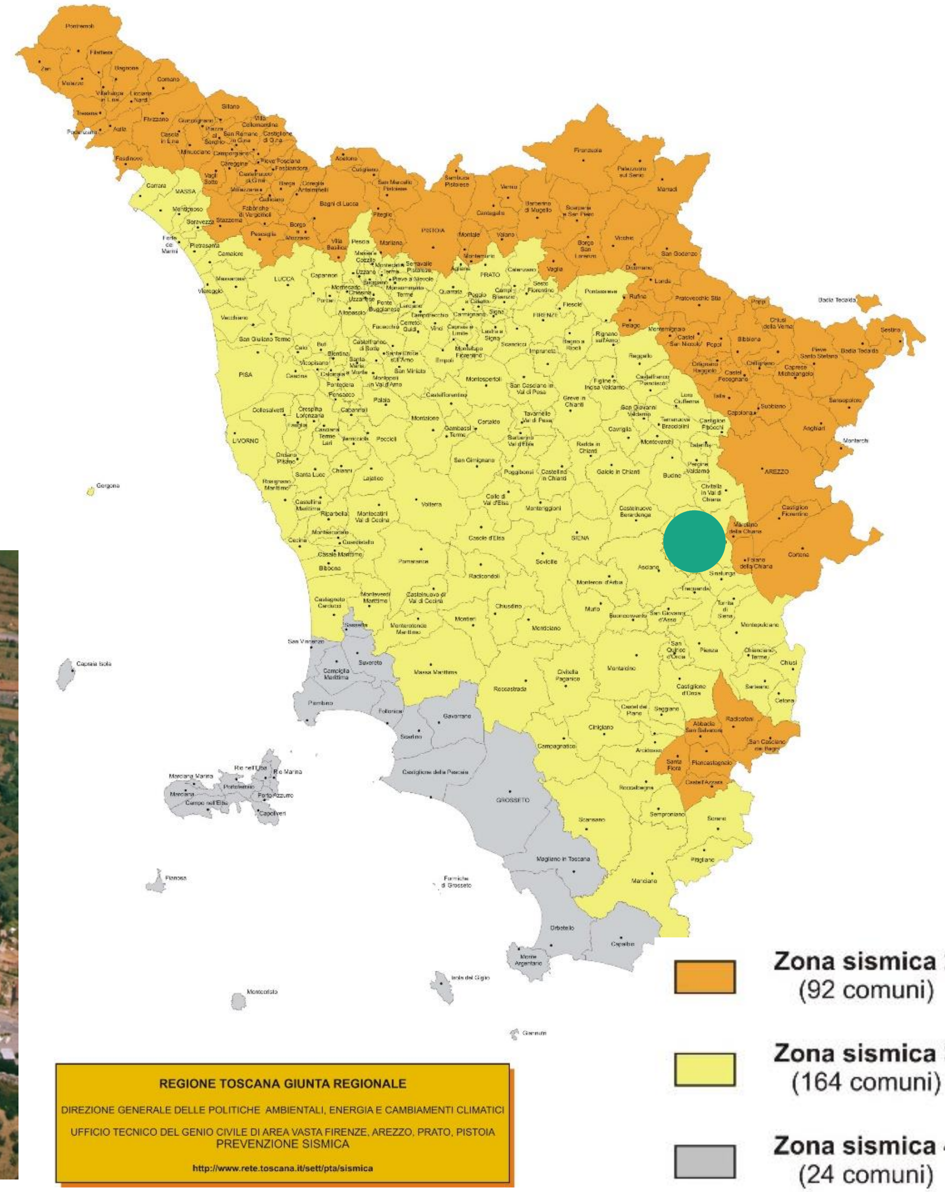
depthmapX

LOCAL-LEVEL: RESULTS

Step 1: extensive data collection and intensive survey

LUCIGNANO

- Province of Arezzo, Tuscany
- 43°16′ 28.3″N 11°44′ 45.65″E
- Property: 61563 m^2
- Population: 479 inhab.
- Seismic zone: 3



LOCAL-LEVEL: RESULTS

Step 1: extensive data collection and intensive survey

290 FACADES

SURVEY FORM FOR MASORNY BUILDINGS

Date
Surveyor(s) FRANCESCA GIULIANI

IDENTIFICATION

Municipality Lucignano (AR)
ID Aggregate[1] SA11
ID Structural Unit[1] SU 242
ID Facade[1] 327
Is it cultural heritage? ☐ Listed ☐ Non listed

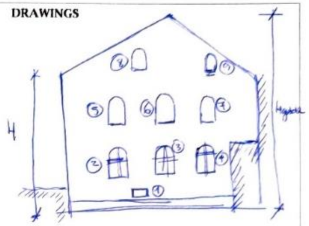
FUNCTION/USE

☐ Annex ☐ Residential
☐ Commercial ☐ Tourism
☐ Deposit/garage ☐ Unused
☒ Public service ☐ Other
Is it an emergency land use? ☒ yes ☐ no
If yes, specify (school, healthcare, public security, municipality, other) Municipality (operative centre)

GEOMETRY OF THE FACADE

General dimensions		$i^{(9)}$	$w_i^{(10)}$ [m]	$h_i^{(11)}$ [m]
$L^{(2)}$ [m]	13,76			
$H^{(3)}$ [m]	10,29	1	1,05	1,00
$H_{gable}^{(4)}$ [m]	13,40	2	1,25	1,85
$T_{bottom}^{(5)}$ [m]	0,67	3	1,25	1,85
$T_{top}^{(6)}$ [m]		4	1,25	1,8
N stories[7]	4	5	0,98	1,26
N openings[8]	9	6	0,98	1,27
		7	0,98	1,27
		8	0,80	1,12
		9	0,80	1,12

DRAWINGS



Elements on the facade[13] (decorations, lamps, cables, equipment, balcony, ports, other) decorations
Id photos[14] 9627-9631

STRUCTURAL MATERIALS (I)

Walls of the facade
☐ Disorganised irregular stone masonry (pebbles, irregular and erratic stones)
☒ Ashlars roughly worked rubble masonry
☐ Squared stone blocks masonry with good texture
☐ Brick masonry and lime mortar
☐ Hollow brick masonry with cementitious mortar
☐ Hollow brick masonry
☐ Hollow brick masonry with dry joints
☐ Hollow concrete or expanded clay masonry
☐ Hollow concrete masonry

Brick holes [%] ☒ <45 ☐ 45-65 ☐ > 65
Mortar quality ☐ L[15] ☒ M[15] ☐ H[15]
Transversal brick connections ☒ L ☐ M ☐ H
Level of maintenance ☐ L ☒ M ☐ H

Connections
☒ Floor-to-wall connections[16]
☒ Wall-to-wall connections (perpendicular walls)[17]

Damage patterns
Walls[18] vertical cracks in the corner
Lintels[19] Corners of the opening

STRUCTURAL MATERIALS (II)

Horizontal structural elements		It it supported by the facade?
1st floor[20]	Wooden	☐ yes ☐ no
2nd floor[20]	Wooden/Masonry vaults	☐ yes ☐ no
3rd floor[20]	Wooden / Vaults	☒ yes ☐ no
Roof[20]	Wooden	☐ yes ☐ no

(wooden, masonry vaults, composite steel and masonry, concrete)

Roof typology[21] ☐ Thrusting ☐ Low thrusting ☒ No thrusting

OTHER FEATURES

Finishing[22]
Non structural elements[23] Chimney, bell tower
Strengthening elements[24] Tie rods

NOTES

SURVEY FORM FOR MASORNY BUILDINGS

Date
Surveyor(s) FRANCESCA GIULIANI

IDENTIFICATION

Municipality Lucignano (AR)
ID Aggregate[1] SA01
ID Structural Unit[1] SU 164
ID Facade[1] 519
Is it cultural heritage? ☐ Listed ☐ Non listed

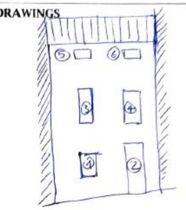
FUNCTION/USE

☐ Annex ☒ Residential
☐ Commercial ☐ Tourism
☐ Deposit/garage ☐ Unused
☐ Public service ☐ Other
Is it an emergency land use? ☐ yes ☒ no
If yes, specify (school, healthcare, public security, municipality, other)

GEOMETRY OF THE FACADE

General dimensions		$i^{(9)}$	$w_i^{(10)}$ [m]	$h_i^{(11)}$ [m]
$L^{(2)}$ [m]	5,05			
$H^{(3)}$ [m]	6,84	1	1	
$H_{gable}^{(4)}$ [m]	/	2	1	2,30
$T_{bottom}^{(5)}$ [m]	0,30	3	1	
$T_{top}^{(6)}$ [m]	0,25	4	1	
N stories[7]	2+ATTIC	5	1	0,53
N openings[8]	6	6	1	0,53

DRAWINGS



Elements on the facade[13] (decorations, lamps, cables, equipment, balcony, ports, other) PORTS, LAMPS
Id photos[14] 7774÷7782

STRUCTURAL MATERIALS (I)

Walls of the facade
☐ Disorganised irregular stone masonry (pebbles, irregular and erratic stones)
☐ Ashlars roughly worked rubble masonry
☐ Squared stone blocks masonry with good texture
☒ Brick masonry and lime mortar
☐ Hollow brick masonry with cementitious mortar
☐ Hollow brick masonry
☐ Hollow brick masonry with dry joints
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Brick holes [%] ☒ <45 ☐ 45-65 ☐ > 65
Mortar quality ☐ L[15] ☒ M[15] ☐ H[15]
Transversal brick connections ☐ L ☒ M ☐ H
Level of maintenance ☐ L ☐ M ☒ H

Connections
☐ Floor-to-wall connections[16]
☒ Wall-to-wall connections (perpendicular walls)[17]

Damage patterns
Walls[18]
Lintels[19]

STRUCTURAL MATERIALS (II)

Horizontal structural elements		It it supported by the facade?
1st floor[20]	Wooden	☐ yes ☒ no
2nd floor[20]	Wooden	☐ yes ☒ no
~~3rd floor~~[20]	~~Wooden~~	☐ yes ☒ no
Roof[20]	Wooden	☒ yes ☐ no

(wooden, masonry vaults, composite steel and masonry, concrete)

Roof typology[21] ☒ Thrusting ☐ Low thrusting ☐ No thrusting

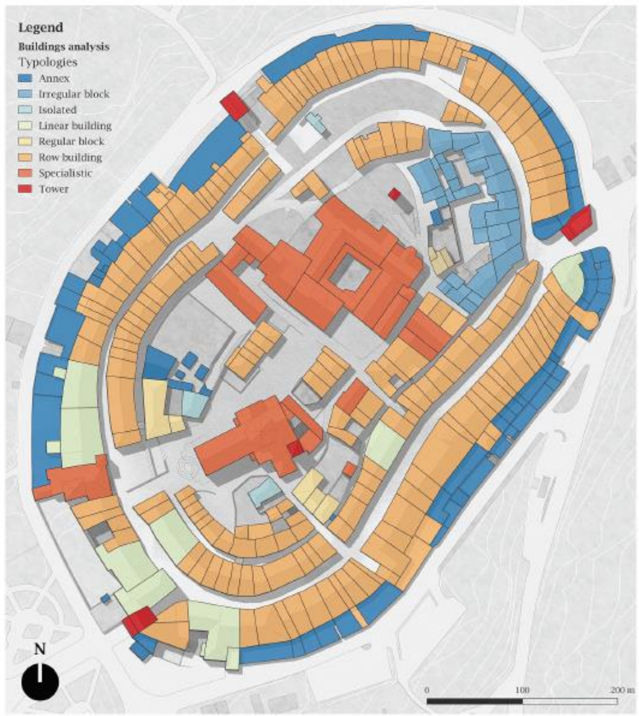
OTHER FEATURES

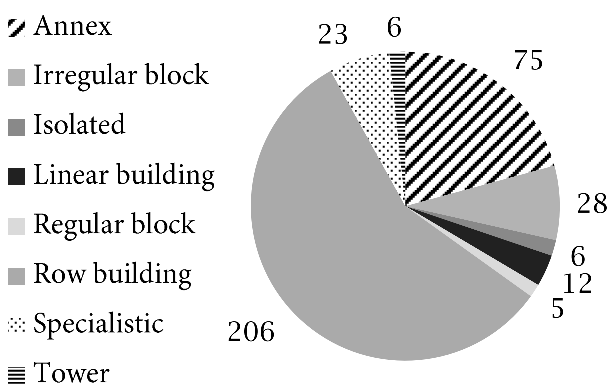
Finishing[22] PLASTER
Non structural elements[23] ROOF TILES
Strengthening elements[24]

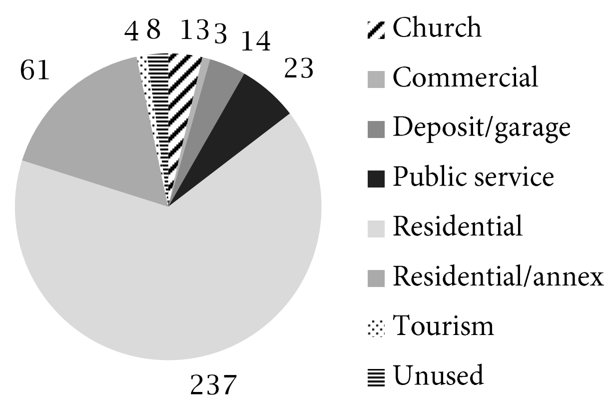
NOTES

LOCAL-LEVEL: RESULTS

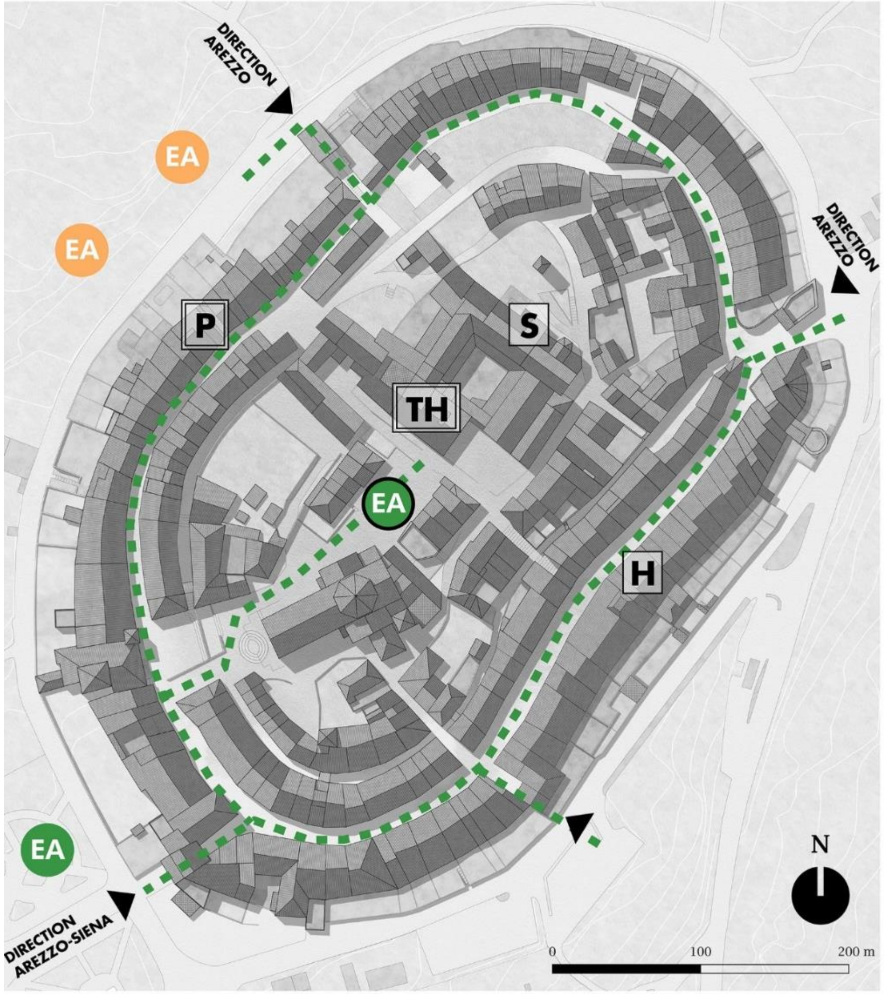
Steps 2: elaboration of data and definition of the database



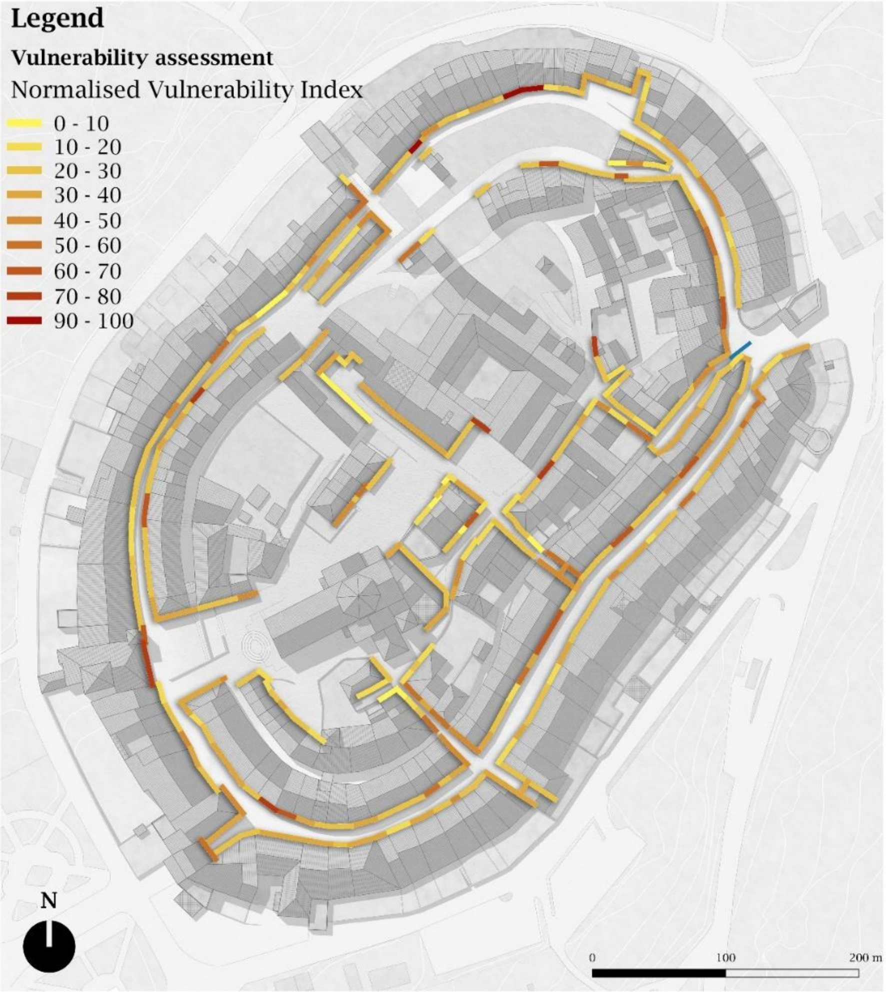




Steps 3a and 4a: functional analysis and emergency scenario



Steps 3b and 4b: vulnerability analysis and damage scenarios



LOCAL-LEVEL: RESULTS

Steps 3c and 4c: spatial analysis and inaccessibility scenarios

Scenario 0: Present-day

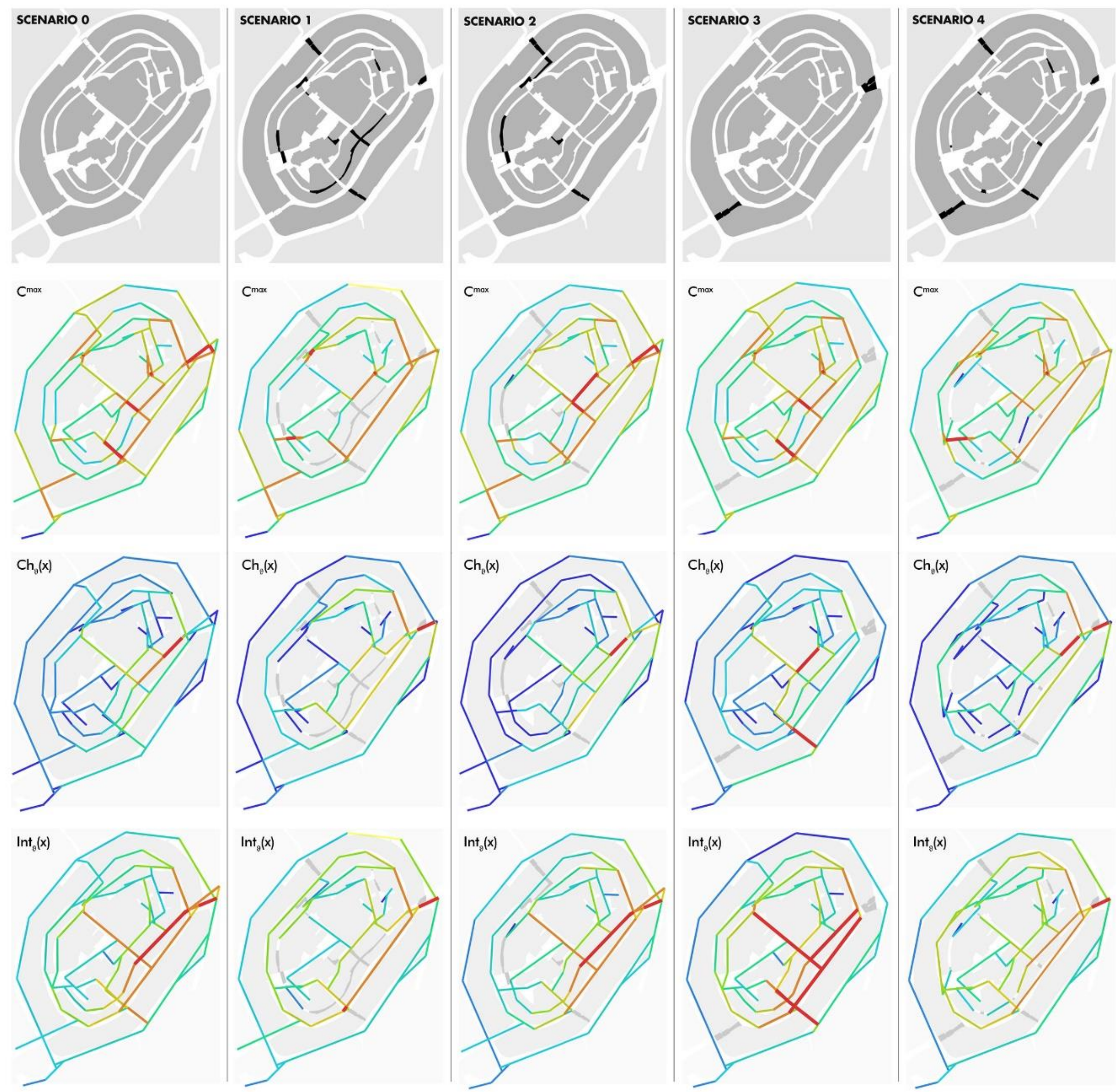
Scenario 1: Emergency services

Scenario 2: Vulnerable categories

Scenario 3: Highest connectivity

Scenario 4: Damage of buildings

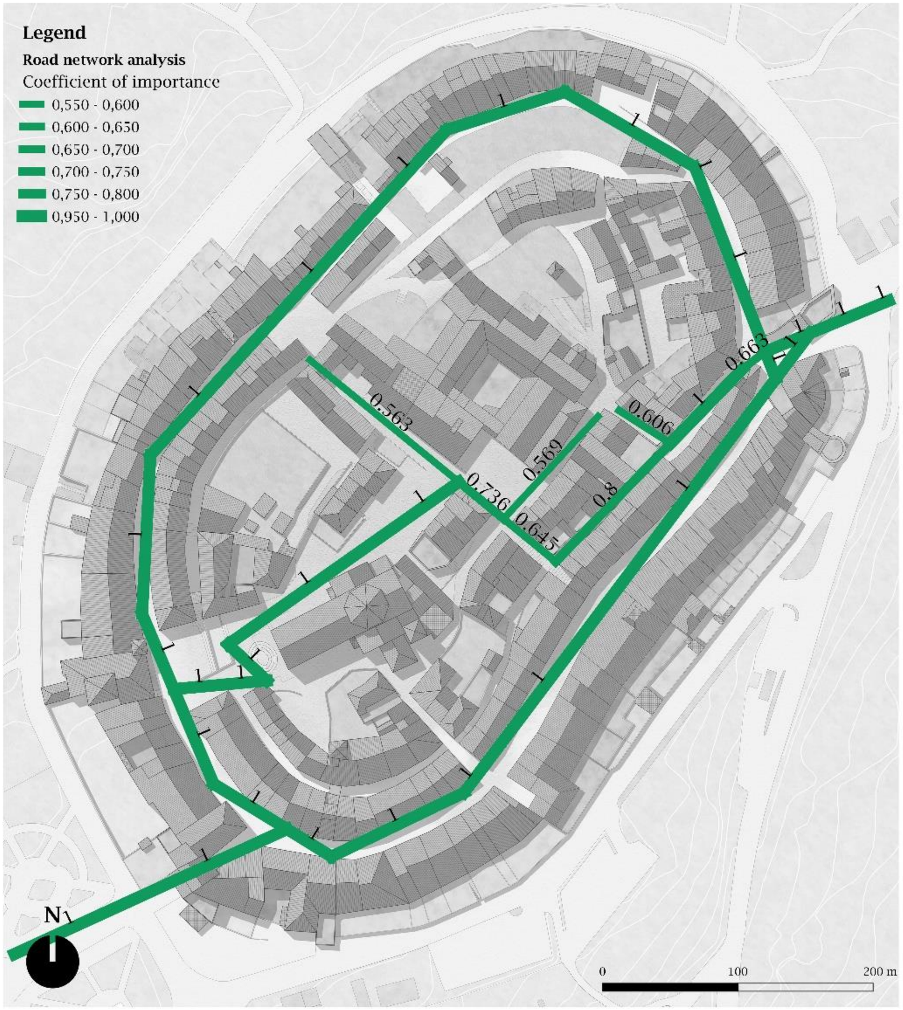
SCENARIO 0 **SCENARIO 1** **SCENARIO 2** **SCENARIO 3** **SCENARIO 4**



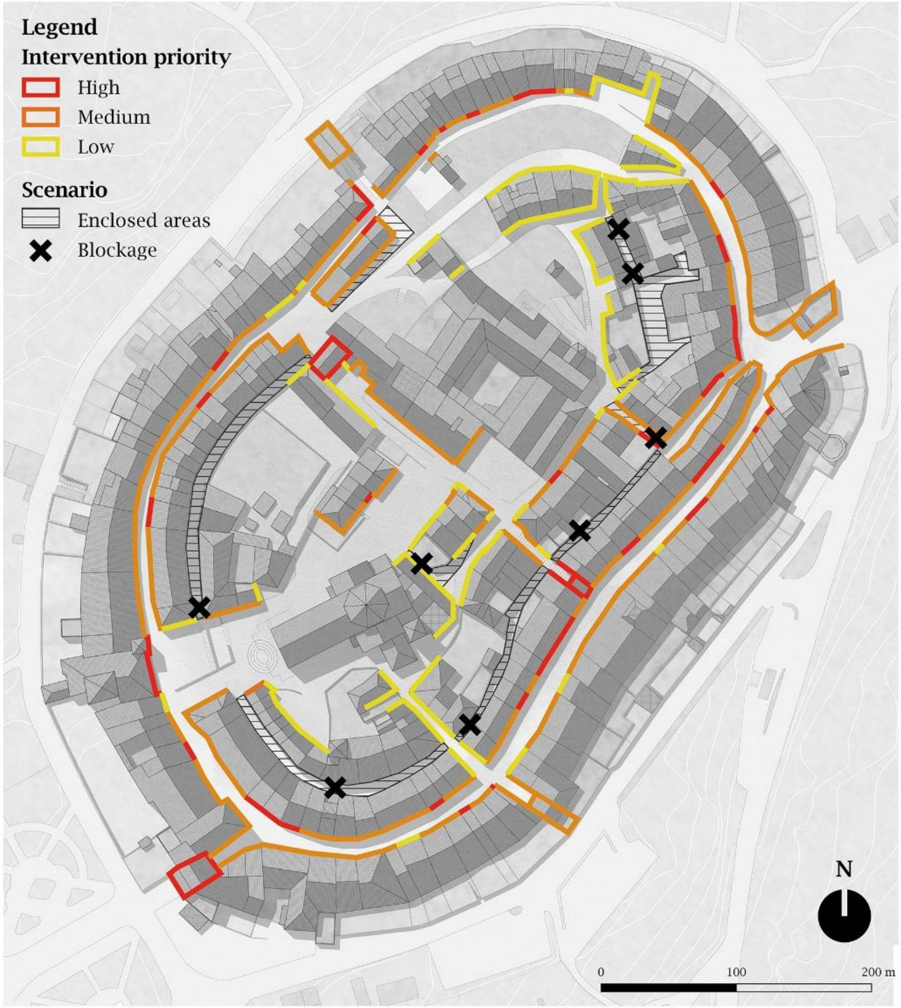
LOCAL-LEVEL: RESULTS

Steps 5: combination of results

COEFFICIENT OF IMPORTANCE (45–th percentile)



INTERVENTION PRIORITIES



RESEARCH CONCLUSIONS

- Lack of preventive planning into Italian historic centres and lack of man-environmental considerations in emergency plans

- This work proposed an integrated methodology to contribute to seismic DRM management by combining multiple disciplines and different approaches with the objective to improve the capacity of the urban system to cope with the event.

MAIN CONCLUSIONS:

- cross-disciplinary and cross-sectorial approach to risk management in historic centres is possible
- contextual knowledge plays a key role
- the integrated multi-step scenario-based methodology has potential for scale-up and replication

FUTURE DEVELOPMENTS:

- Evaluate multi-hazard scenarios
- Include data regarding the exposure by means of statistical data from conventional sources and big data from emerging sources
- Implementation on a wider set of case studies
- Numerical explorations on the seismic response of SAs to identify interventions
- Behavioural aspects of pedestrian evacuation simulations