A simplified procedure for risk assessment of cultural heritage: definition and application to case studies

Michelangelo LATERZA[1], Michele D'AMATO[2], **Daniela DÍAZ[3]**

[1, 2, 3] DICEM, Dept. of European and Mediterranean Cultures (Architecture, Environment and Cultural Heritage), University of Basilicata, Matera, Italy
[1] michelangelo.laterza@unibas.it
[2] michele.damato@unibas.it
[3] daniela.diaz@unibas.it

Abstract: Nowadays comprehensive management plans are needed for conserving and protecting the immovable cultural heritage in high natural risks-prone areas.

In a previous work a seismic risk assessment procedure was proposed, established by applying three different tools addressed to define: seismic vulnerability assessment, hazard mapping and prioritizing assistance based on cultural value.

In this paper some applications to case studies of the proposed procedure are shown. In particular, are performed the seismic risk evaluations of two Chilean and two Italian old masonry churches. The seismic vulnerability has been evaluated taken into account some structural indicators such as: the building position and the characteristics of its foundations; geometry in plan and in elevation; distance between walls; the type and quality of the resistant system; horizontal and covering structures; the conservation status; alterations in the construction system and in the environment; vulnerability to fire and the presence of secondary elements that could fall after an earthquake.

The seismic hazard is evaluated also including other threats such as: landslides, erosion, physical stress, air pollution, socio-organizational and scarce maintenance, making a hierarchy according to the severity of potential damage on the Cultural Property that can increase seismic risk.

Keywords: seismic risk assessment, threats, seismic vulnerability, religious architecture.

1. Introduction

In geographic areas with high risk of natural disasters, comprehensive risk management plans for the conservation of cultural property have not been completely developed yet. However, it is noticed a growing interest in disasters prevention, mainly following the agreement of the United Nations (1989) to declare the last decade of the twentieth century as the International Decade for Disaster Reduction. Thus, countries have tried to change the population reactive attitude by increasing public awareness of the hazards and, consequently, reducing the vulnerability of people and infrastructures.

Disaster prevention in the field of built heritage conservation has been addressed by developing principles and manuals for risk management settled by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Council on Monuments and Sites (ICOMOS), the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and the Getty Conservation Institute, and also by implementing prevention programs as *Carta del Rischio* (*Istituto Superiore per la Conservazione ed il Restauro* 1992) in Italy and the Disaster Prevention Program on Cultural Heritage (*PrevINAH* 2002) in Mexico. However, some problems in the implementation of these methods still remain, mainly due to the fact that they develop universal principles without a comprehensive assessment of the threats and the related vulnerabilities of each cultural property, and the lack of precision on the information's management.

Nowadays, it is assumed that a risk is "the combination of the probability of an event occurring and its negative consequences" (UNISDR 2009:29), which can be defined as:

Risk (R) = Vulnerability (V) x Hazard (H)

Where the hazard is "a phenomenon, substance, human activity or dangerous condition, which can result in death, injury or other health impacts, as well as property damage, loss of services, social disruption and economic or environmental damage" (UNISDR 2009:5). Moreover, vulnerability is defined as "the characteristics and circumstances of a community, system or property that make it susceptible to the damaging effects of a hazard" (UNISDR 2009:34). Therefore, vulnerability is always evaluated regarding a particular threat, which in this paper will be the seismic hazard.

In a recent work developed by Díaz (2015) risk assessment tools have been proposed based on a comparative analysis which systematizes the contributions of the above mentioned manuals, aiming to create risk maps at territorial level for programing the state and private action, to increase the resilience of Cultural Property. These tools address the risk assessment at establishing a correlation between the identification of threats and vulnerabilities, and the causes of historic buildings deterioration, based on the document developed by De Angelis (1972) for the ICCROM. There are several factors causing monuments deterioration, which generally act together and can be schematically divided into two groups: the intrinsic factors related to the origin and the nature of the monument, and extrinsic factors related instead, to site conditions. By linking this approach to risk assessment, it was possible to determine that extrinsic factors correspond to threats, while the intrinsic factors are related to the vulnerability. Starting from these considerations, new tools were defined: *Tool 1: Seismic vulnerability assessment form* (V) *and Tool 2: Description, hierarchy and hazard mapping* (H). These tools are described and applied in the following paragraphs in four case studies: San Francisco Church in Chiu Chiu and Laonzana Church in Huara, Chile; San Vito Church in Ostuni and St. Augustine Church in Matera, Italy.

2. Tool 1: Seismic vulnerability assessment form

The first tool proposed in Díaz (2015) is addressed to assess the seismic vulnerability and consists on a form to evaluate the structural seismic vulnerability, where the considered parameters are defined from a comparative analysis of documents on structural analysis and post-earthquake evaluation of damage forms.

The parameters for assessing the seismic vulnerability are 13 and are described as follows: the *position of the building and its foundations* assesses the soil type and slope (if any); the *floor plan configuration or geometry* measures the asymmetry of the building that increases its vulnerability to an earthquake; the *elevation configuration* evaluates the building stories, mass distributions and continuity of resistant elements throughout the height; the *distance between the walls* assesses the slenderness of the walls, the out of plumb, the openings location, the excessive length in plan between two transversal walls, among others; and the *non-structural elements* parameter evaluates the accessories, projections or overhangs that could fall in an earthquake.

On the other hand, the parameters assessing the *type, organization and quality of the resistant system* evaluate the constructive system, the material, the lock between orthogonal walls and the connection between walls and floors by the means of horizontal structures executed with compatible materials. Regarding the *horizontal structures* and *roofing* parameters, they assess the deformability in the plane, the material compatibility, the thrusts on the walls and suitable connections between walls and roof. Finally, the *conservation status* evaluates the building visible condition in terms of damage; the *alterations in the construction system* and in the *environment* evaluate the negative interventions that have increased the vulnerability; and the *vulnerability to fire* evaluates the presence of flammable ornaments and furniture, lack of compartmentalization and internal divisions, dangerous activities, etc.

Fig. 1 shows the Tool 1 diagram, presenting the parameters for assessing the seismic vulnerability divided into three groups (in green) as follows: position of the building; structure characteristics; and conservation status. In both sides of the main column the parameters related to the main group are shown (in purple), and the source or reference (in white) is shown next to each parameter.

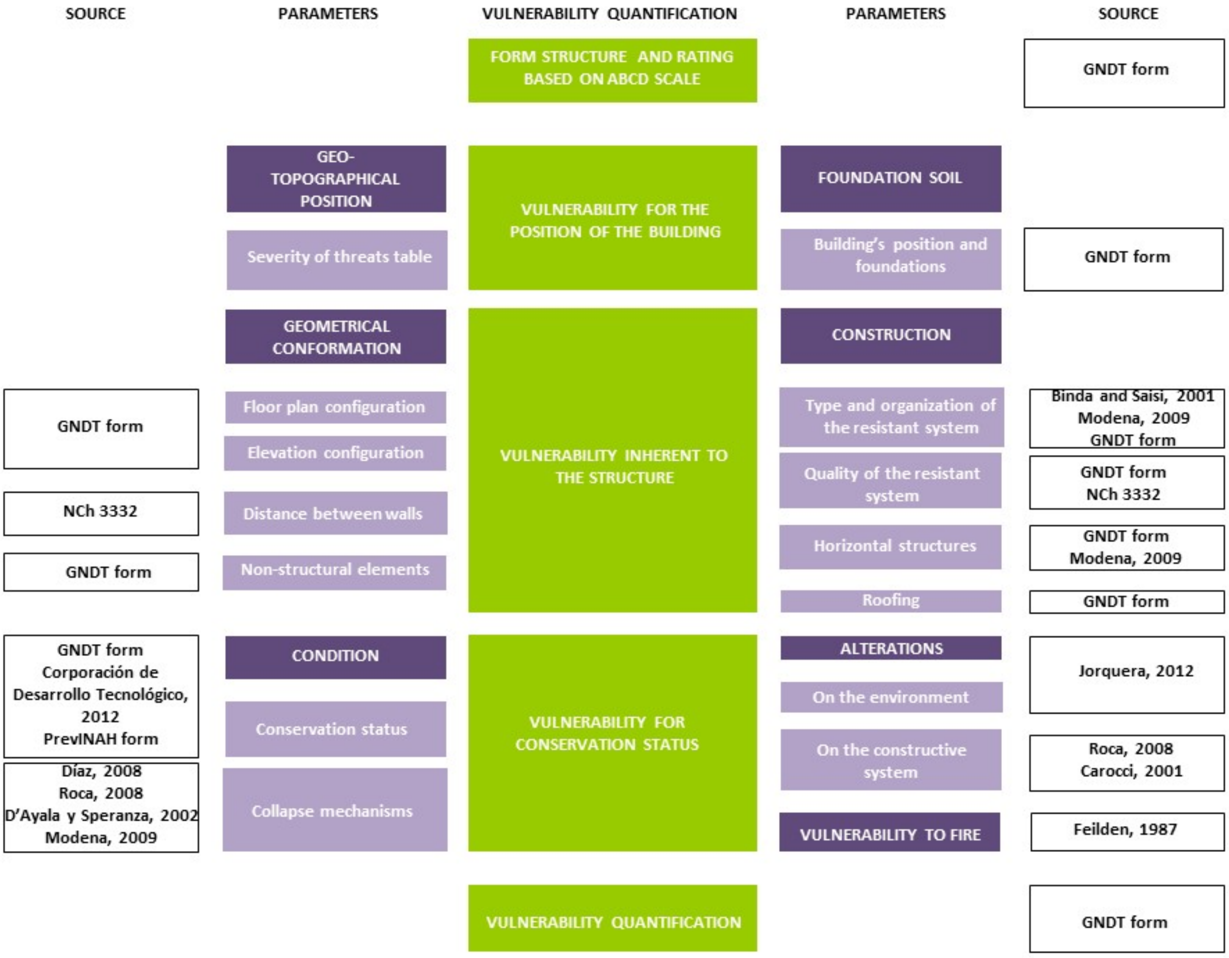

Figure 1 –Tool 1: Seismic vulnerability assessment (Díaz 2015)

Each parameter is classified on the scale A, B, C and D, where A indicates a very low vulnerability and D a very high vulnerability of the building by a numerical value. The values and weight of each parameter were based on the GNDT form (DGPT 2012), which proposed a table for the vulnerability quantification, taking into account the varying importance of each parameter for the purposes of seismic behavior of the structure. Since in the Díaz (2015) procedure the parameters were modified and increased with the aim of adapting the form for assessing the Cultural Property, the values of the table were changed but keeping the proportions of those proposed by the GNDT (Table 1).

Thus, the vulnerability index is defined with the following relationship,

$$VI_j = \sum_{i=1}^{n} v_{j,i} p_i$$

where $v_{j,i}$ is the value of the parameter that takes into account its characteristics and its influence on the behavior of the building; and p_i is the weight that takes into account the relative importance of the parameter in the evaluation of the building.

Table 1 – Rating and weight of parameters to define seismic vulnerability index (Díaz 2015)

Parameters		Class				Weight
		A	B	C	D	
1	Position of the building and foundations	0	1,35	6,73	12,12	0,75
2	Floor plan configuration or geometry	0	1,35	6,73	12,12	0,5
3	Elevation configuration	0	1,35	6,73	12,12	1,0
4	Distance between walls	0	1,35	6,73	12,12	0,25
5	Non-structural elements	0	0	6,73	12,12	0,25
6	Type and organization of the resistant system	0	1,35	6,73	12,12	1,5
7	Quality of the resistant system	0	1,35	6,73	12,12	0,25
8	Horizontal structures	0	1,35	6,73	12,12	1,0
9	Roofing	0	1,35	6,73	12,12	1,0
10	Conservation status	0	1,35	6,73	12,12	1,0
11	Environmental alterations	0	1,35	6,73	12,12	0,25
12	Construction system alterations	0	1,35	6,73	12,12	0,25
13	Vulnerability to fire	0	1,35	6,73	12,12	0,25

The seismic vulnerability index is then classified in a range proposed by Díaz (2015): low vulnerability: $0 < V \leq 10.81$; medium vulnerability: $10.81 < V \leq 55.52$; and high vulnerability: $55.52 < V \leq 100$. Finally, the seismic vulnerability index is multiplied by the seismic hazard index to calculate the seismic risk.

3. Tool 2: Description, hierarchy and hazard mapping

The second tool developed in Díaz (2015) is addressed to the hazard mapping and is based on the analysis of documents in the field of territorial planning and heritage conservation. It performs a global analysis of threats that may affect cultural property aiming to evaluate the worst scenario, where each of the threats is considered with the greatest magnitudes evaluated with historical information. The procedure proposed the assessment of the following threats: seismic, hydro-meteorological, volcanic, landslides, erosion, physical stress, chemical, air pollution, socio-organizational and serious demographic decline with the consequent lack of maintenance. These threats are then classified and prioritized based on the severity of damage that they may cause on the building.

The diagram in Fig. 2 shows the classification of the threats into three main groups (in green): natural hazards of occasional action; threats of physical nature; and man-made and chemical hazards. In both sides of the main column the parameters related to the main group are shown (in purple), and the source or reference (in white) is shown next to each parameter.

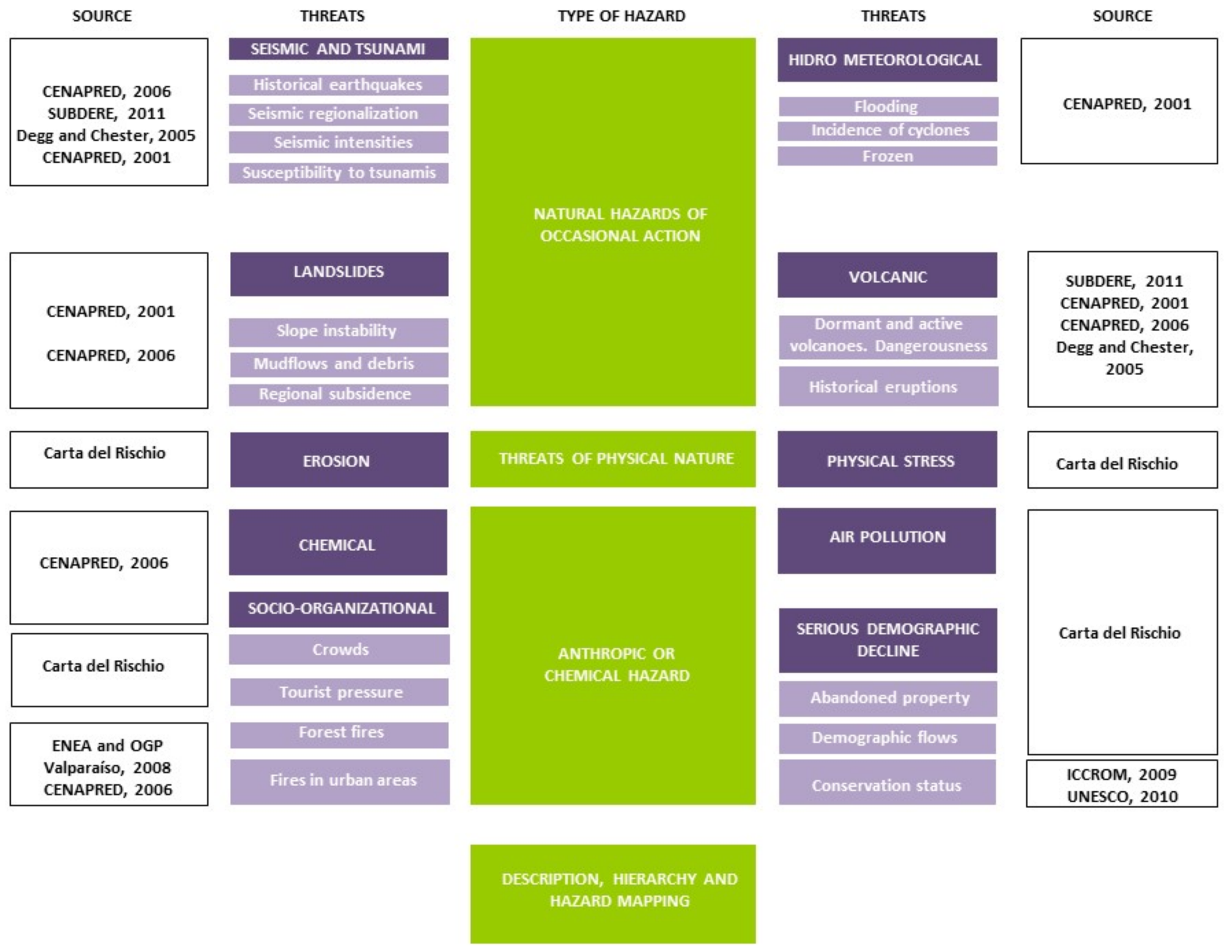

Figure 2 – Structure of Tool 2: Description, hierarchy and hazard mapping (Díaz 2015)

Based on this methodology, the current analysis aims to assess only the seismic risk; therefore, the *seismic* threat (Maximum Mercalli Intensity) will be assessed as well as the *landslide* threat, because is a likely consequence of a strong earthquake, and also the continuous processes threats: *erosion, physical stress, air pollution, socio-organizational and serious demographic decline (lack of maintenance)*, since their main consequence is the material damage of the Cultural Property.

The first step to assess *seismic threat* includes the research of historic earthquakes, their intensity, maximum acceleration of the ground and distance from the epicenter, and also the danger of tsunami according to the study of affected areas. The *landslide threat* is analyzed considering: topography and geometry of the slopes; geological stratification distribution and stress status; mechanical properties of the soil; ordinary and extraordinary rainfall; surface and underground hydrology; and identification of anthropogenic interventions which may have caused: changes in the pressure system of underground water, in the geometry of the slope or in the rise of overload, and deforestation without technical evaluation. By analyzing these parameters, the worst scenario is established based on the instability of natural slopes, the likely presence of mud and debris flows, and regional or local landslides.

Regarding the continuous processes threats, they occur at least one time a year and are mainly related with the geographical position, the weather and the social context. The *erosion threat* parameter assesses the average and maximum rainfall, the distance to the coast, the relative humidity and the direction and speed of prevailing winds that may provoke material deterioration. The *physical stress threat* assesses: the average and maximum rainfall, maximum and minimum temperatures, thermal oscillation and solar lighting, aiming to assess the likely damage in the materials by a strong oscillation of temperature, and the confluence of raining and freezing (temperatures below 0°) that may provoke the icing of water particles and the consequent disintegration or cracking of materials. On the other hand, *air pollution threat* assesses: vehicular congestion zones; location of airports and seaports; highways and daily circulation of cars; and concentration of air pollution, in order to evaluate the likely blackening of materials or its dissolution by acid rainfall.

Socio-organizational threat parameter analyzes the overload or damage on the monuments for the presence of crowds of people by analyzing touristic pressure, and it also analyses the likeliness of fire by studying: forest fuel (presence of vegetation); weather conditions (presence of heat and wind); the exposure to the sun of the hills slopes; the continuity of construction and urban blocks; and the presence of defective electric wires or wooden buildings. On the other hand, the likely lack of maintenance in monuments is analyzed by studying the *serious demographic decline* by identifying the location of abandoned buildings and conservation status.

All these parameters are analyzed for establishing the worst scenario based on historical information. They are then classified depending of the severity of damage that the scenario may cause in the monuments which may be: no damage, low or gradual, or catastrophic. Every parameter has a score based on the influence of the threat, as a site effect, in the seismic behavior of the building (Table 2).

Table 2 – Rating and weight of parameters to define seismic hazard index (Authors)

Parameters		**Severity of damage**		
		No damage / No hazard	**Low or gradual**	**Catastrophic**
Sporadic events	Maximum Mercalli Intensity	0	0.20	0.40
	Landslide or rock fracture	0	0.15	0.25
Continuous processes	Erosion	0	0.05	0.10
	Physical stress	0	0.05	0.10
	Air pollution	0	0.01	0.05
	Socio - organizational	0	0.01	0.05
	Serious demographic decline: lack of maintenance	0	0.01	0.05

Afterwards, the seismic hazard index is obtained by adding the 7 parameters, with a result ranging from 0 to 1, and then it is multiplied by the seismic vulnerability index to calculate the seismic risk.

4. Application to case studies

In order to apply this methodology four churches will be analyzed, sited in Chile and Italy.

The church of San Francisco in Chiu Chiu, sited in Antofagasta Region in northern Chile, is formed by an only nave with attached chapels. The walls and the bell tower are built in adobe masonry with mud plaster and lime, and the roof has a cactus wood structure and mud plaster as finishing. On the other hand, the Church of Laonzana is sited also in northern Chile, in the Tarapaca Region. It is formed based on a Latin cross floor plan with an only nave, has a sacristy and a chapel in the transept, and an altar. The bell tower was built with stone and mud plaster but was later modified with a wood structure to contain the bell. This church was seriously damaged after the 2005 earthquake in Chile, collapsing more than 60% of its structure and rebuilt in 2012 with iron and concrete systems. Therefore, the vulnerability analysis will consider the state of the church before the seismic event, considering the adobe elements.

Regarding the Italian case studies, the Church of San Vito in Ostuni is sited in Puglia Region, while the Church of St. Augustine of Matera is sited in Basilicata Region, both in southern Italy. They have a basilica floor plan with an only nave. Their walls, dome and bell tower are made of limestone masonry and the nave is covered by a vault. The results of the application to the study cases are shown in Table 3.

Table 3 – Rating and weight of parameters to define seismic risk (Authors)

Parameters			Chilean churches		Italian churches	
			San Francisco	**Laonzana**	**San Vito**	**St. Augustine**
VULNERABILITY	1	Position of the building and foundations	A	B	B	B
	2	Floor plan configuration or geometry	D	D	C	C
	3	Elevation configuration	A	A	C	A
	4	Distance between walls	D	C	D	C
	5	Non-structural elements	A	A	C	C
	6	Type and organization of the resistant system	B	D	D	C
	7	Quality of the resistant system	B	D	C	A
	8	Horizontal structures	C	D	A	A
	9	Roofing	C	C	B	D
	10	Conservation status	A	C	B	A
	11	Environmental alterations	B	C	A	B
	12	Construction system alterations	A	B	A	D
	13	Vulnerability to fire	B	B	C	B
		Seismic vulnerability index	**25.6**	**57.9**	**40.0**	**33.7**
HAZARD	1	Maximum Mercalli Intensity	0.40	0.40	0.20	0.20
	2	Landslide or rock fracture	0.25	0.25	-	0.15
	3	Erosion	-	0.10	0.10	-
	4	Physical stress	0.10	0.10	-	-
	5	Air pollution	-	-	0.05	0.05
	6	Socio-organizational	-	-	0.05	0.05
	7	Serious demographic decline: lack of maintenance	-	0.05	-	-
		Seismic hazard index	**0.75**	**0.90**	**0.40**	**0.45**
		TOTAL SEISMIC RISK (V x H)	**19.20**	**52.11**	**16.00**	**15.16**

5. Conclusions

In this paper a new procedure for the seismic risk assessment of cultural heritage has been proposed. The proposed simplified approach might be used in a territorial scale for planning the preventive conservation of the Cultural Property, because allows us with a final score, to define a classification of interventions based on the specific vulnerabilities and hazards of the cases under consideration.

In particular, for the four churches considered it has been evidenced that all of them have a medium seismic vulnerability. However, the Italian churches built with stone masonry have similar scores, while there is an important difference between the Chilean churches, although they have the same architectural typology and constructive system in adobe. The main difference between the Laonzana Church and the others is due to the type, organization and quality of the resistant system, because there were not efficient connections between the adobe walls or between the walls and the roofing, and also the adobe was deteriorated by weathering. Moreover, the construction system of this church and its environment had been modified.

Regarding seismic risk assessment, the results in terms of vulnerability range evaluated in Tool 1 are increased by adding the results of Tool 2, which evaluates the worst seismic hazard scenario. Regarding the Chilean churches, the vulnerability of the Church of Chiu Chiu to the seismic threat is increased by its high seismic location, and also because there might be a catastrophic scenario caused by rainfall, which produces the Loa River flood and mudslide every year within 10 meters from the church, which is also sited on unconsolidated material and may have differential settlement. On the other hand, the Church of Laonzana has the major seismic risk among the case studies, mainly for the landslide threat but also for the erosion threat. The rainfall in the highland winter may change the mechanical properties of the soil, which is made of unconsolidated material, and this instability may be increased by the extreme temperatures, going from 0° to 30° in the same day producing rocks physical weathering, and by non-regulated housing constructions producing humidity in the subsoil.

The seismic risk of the Italian churches is different, because the Church of Ostuni is located in a low seismic area without landslide threat, while the Church of St. Augustine has a higher risk mainly for the likely fracture of the soil rock with a strong earthquake, because it is sited in the ravine border of Gravina River in Matera, which is formed by a hard dolomitic calcareous, but fractured in layers and benches, and often with karst, and it is surrounded by geological faults.

Acknowledgments

This research herein presented is granted by the ELARCH scholarship and mobility, a project funded under the Erasmus Mundus Action 2 Partnership (EMA2) by the European Commission, and coordinated by the University of Basilicata (www.elarch.org).

References

De Angelis, G. (1972) *Guida allo studio metodico dei monumenti e delle loro cause di deterioramento.* ICCROM / University of Rome, Rome (free translation of Juana Gomez Badillo to the National School of Conservation, Restoration and Museology "Manuel del Castillo Negrete", Mexico City).

Díaz, D. (2015). *Diseño de herramientas de evaluación del riesgo para la conservación del patrimonio cultural inmueble. Aplicación en dos casos de estudio del norte andino chileno*. Master's Thesis on Conservation and Restoration of Cultural Property, National School of Conservation, Restoration and Museology "Manuel del Castillo Negrete", Mexico City.

Direzione Generale delle Politiche Territoriali, Ambientali e per la Mobilità Coordinamento Regionale Prevenzione Sismica (DGPT) (2012) *Criteri per l'esecuzione delle indagini sugli edific in muratura, la relazione técnica e la compilazione della scheda di vulnerabilità II livello GNDT/CNR con riferimento alle nuove norme tecniche per le costruzioni* (D.M. 14 gennaio 2008), Programma regionale VSM, Regione Toscana, Giunta Regionale.

ICR1992, Istituto Superiore per la Conservazione, Carta del Rischio, http://www.cartadelrischio.it, accessed in February 24, 2016.

Instituto Nacional de Antropología e Historia (2002). *Programa de Prevención de Desastres en Materia de Patrimonio Cultural, PrevINAH*. INAH, México City.

UNISDR, Terminology on disaster risk reduction, published by the United Nations Office for Disaster Risk Reduction (UNISDR), Geneva, Switzerland, 2009.

United Nations, Resolution 44/236 Decenio Internacional para la Reducción de los Desastres Naturales, http://www.snet.gob.sv/noticias/Redesas2002.htm, accessed in February 24, 2016.