ELARCH Project: Prioritization of threats of cultural heritage for the development of a hazard map. The case study of Aragon's Castle, Venosa (Italy).

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Abstract: In recent years it has highlighted global interest in disaster prevention and risk mitigation, and the importance of cultural heritage and conservation. According to the literature, the risk is directly linked to two variables: vulnerability and threat, the first related to intrinsic causes of the element and the second to external phenomena.

This work is aimed to risk analyses of the Castle of the municipality of Venosa, located in the region of Basilicata (Italy). By studying the threats of the area, based also on historical records of the territory, it has been developed a classification of them, categorized in according to their impact level that could be catastrophic, mild or no harm. Development of threats map by using geographic information systems (GIS) is also discussed.

Keywords: Threat, cultural heritage, risk, map.

1. Introduction.

In recent decades it has been increased the interest in the study of natural and anthropic risks in the cultural heritage and their mitigation, changing the concept of action reactive to a preventive stance. Risk is "the combination of the probability that an event occurs and its negative consequences" (UNISDR, 2009), commonly knowing in scientific literature as presented in equation 1.

$$\text{Risk} = \text{Threat} \times \text{Vulnerability} \quad (1)$$

Where the threat is "a phenomenon, substance, human activity or dangerous condition that can result in loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage", and vulnerability are "the characteristics and circumstances of a community, system or asset that makes it susceptible to the damaging effects of a threat" (UNISDR, 2009). For cases of uncontrollable natural phenomena such as an earthquake, it proceeds to reduce vulnerability or increase the impact strengths in the cultural properties (Díaz Fuentes, 2015).

In the cultural heritage camp, irreplaceable losses continue to occur throughout the world as a result of natural or man-made disasters. The development of risk prevention measures needs to be based on adequate knowledge about the threats that these assets facing. However, for most countries, carrying out a multi-hazard risk analysis for a large number of cultural heritage assets requires efforts and budgets that are frequently unavailable. Therefore, assessing the risks for a large number of assets with limited resources is only feasible when based on simple methodologies (Romao, Pauperio, & Pereira, 2016).

The study and analysis of the threat variable for a cultural object requires many efforts and knowledge of all boundary conditions. For example a methodology may be found in (Agapiou, et al., 2015) or recently an alternative approach has been developed in (Díaz Fuentes, 2015), in it was considered various aspects provided by sources as the “risk map”, the CENAPRED, the "guide analysis of natural risks for land use planning" among others.

By using Geographic Information Systems GIS, hazard maps locating the threats that could affect the cultural heritage may be developed, where historical data describe the severity of each threat. Then it proceeds to the analysis of prioritization based on historical facts and their severity on the historical buildings, placing it into one of the three possibilities: No damage, mild or catastrophic.

In this study an application of this approach is described and applied to the case study of the municipality of Venosa, located in the region of Basilicata in Italy.

2. Literature review

2.1. Threat

A hazard or threat is the change in a situation or a series of situations that has the potential to cause harm or property loss. A disaster is the collapse of a series of social functions that cause loss of life, materials, economy, or the environment. In addition to the possibility of life and property loss, the meaning of disaster also includes damage or loss of the general value of a country’s cultural heritage and the ecological system and its environment (UNESCO, 2010). UNESCO notes that the disaster risk to cultural heritage comes from external and internal causes. The external cause is the disturbance or damage to cultural heritage sites caused by typhoon, tsunami, destructive sabotage, or war. The internal cause is the fragility of the structure or materials of cultural heritage and their sensitivity to the environment.

Ghose divided the disaster risks to cultural heritage into unpredictable disasters and predictable deterioration (Ghose, 1999). Unpredictable disasters include disasters caused by natural phenomena and human behaviors. The five categories of natural disasters are geophysics, meteorology, hydrology, climatology, and biology. Man-made disasters include fire, accidents and military conflicts. Predictable deterioration includes vandalism, illicit traffic in cultural property, and environmental deterioration (Fig. 1 (Jung, 2010)).

Moreover, in the area of risk management, it has created the concept of multi-hazard, which are those that relate to the analysis of the various hazards and trigger cascading effects that threaten the same elements exposed with or without a temporal coincidence (Komendantova, et al., 2014). Interactions between threats can be considered a probabilistic analysis of historical databases that already take into account events cascade, for example, databases that determine the possibility of an earthquake causing a tsunami (Marzocchi et al. 2012).

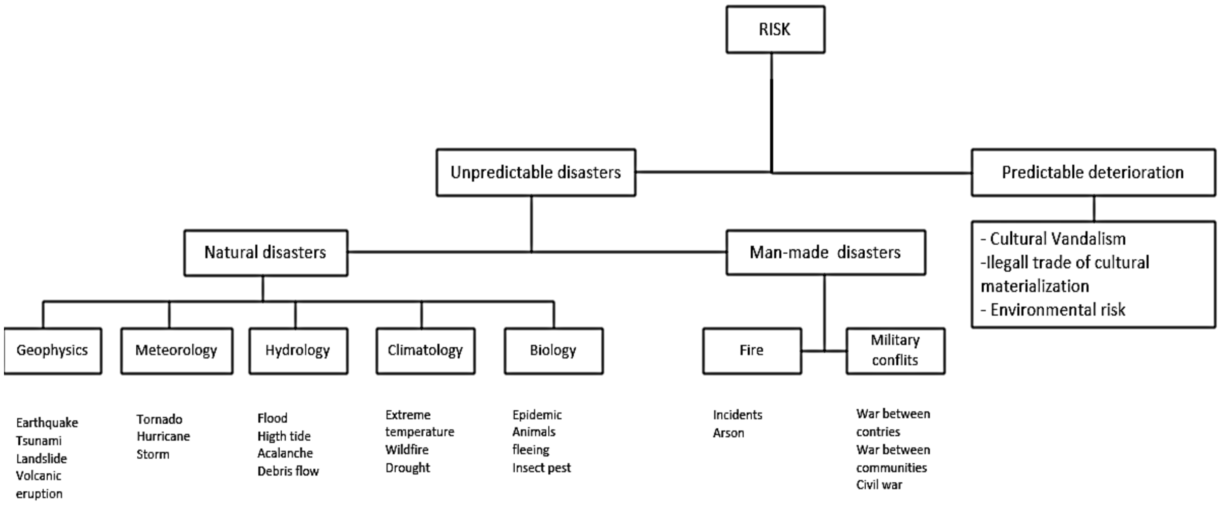


Fig. 1. Schematic diagram of common disasters and risks to cultural heritage.

Additionally, in the field of cultural heritage, it is necessary to evaluate other variables that are the result of a cascade effect, such as the demographic decline, which could result in lack of maintenance and finally the abandonment of cultural property.

2.2. Hazard Map.

A hazard potential map or a hazard map is presently an important and sensible tool of basic foundation for developing various strategies for disaster adjustment and relief, indicates the setting of hazard situations, warning values, potential hazard areas, the main landmarks, and the possible scope of effect (Wang et al., 2011). It is the substantiation of risk assessment on the map, which helps responders plan projects and strategies for all phases of disaster. The predictable or unpredictable effects of disasters will thus be reduced (Wang J.-J. , 2015).

With regard to risk maps, for example may be mentioned the ones proposed by CENAPRED in Mexico and the "Risk Map" in Italy, based on GIS and where are mapped the main threats that cause impairment to equity (Díaz Fuentes, 2015).

In 2011 in Chile were developed the Guide Analysis of Natural Hazards and Territorial Planning, where one of the main emphasis of this document, was the mapping of natural hazards, based on a methodology that considered historical aspects and scope of developed natural disasters. For their case in particular, it focused on threats that affect the country, such as are the natural hazards caused by environmental factors (Secretaría de Desarrollo Regional y Administrativo, 2011).

A highlight of the hazard maps contribution is one that Maria Jose Jimenez has proposed in the article called The map Euro-Mediterranean seismic hazard, it is incorporated into hazard mapping the interaction between soil type and frequency. In that way, Jimenez proposes to map factors as the point of ground, acceleration and spectral acceleration corresponding to portions of bandwidth energy radiated by an earthquake, for different return periods and soil conditions (Jimenez, 2008).

In (Agapiou, et al., 2015), several natural and anthropogenic hazards have been mapped using different remote sensing data and methodologies. The results from each hazard were imported into a GIS environment in order to examine the overall risk assessment based on the Analytic Hierarchy Process methodology. In the document was obtained a threat map of a cultural heritage with all threat studied by them. However, the scale at which it developed was extensive and developed a general scale of the territory.

Moreover, the use of hazard maps has been used mostly for two types of threats, seismic threats and threats by climatic effects, as they are phenomena that impact greatly architectural heritage and which generally tools used GIS to finally be represented in maps.

2.3 GIS as tool of cultural heritage.

Geographic Information System (GIS) is the new emerging field and grows at very rapid pace. Remote sensing, aerial photography, cartography, surveying and other field instruments for attribute data collection contributes to the data acquisition, allowing the interaction among many disciplines summarizing the information in one system, becoming in a smart tool in the modern age.

The use of GIS for cultural heritage management purposes, has grown considerably in the last decades, becoming a very widespread toolkit among preservation specialists. Due to the very spatial nature of the discipline, this technology rapidly opened new possibilities such as the cultural heritage management, making the most effective environment to perform technical historical and assessment of the element. (Campanaro, 2016).

For the specific case of hazard maps, GIS allows the inclusion of mapping data of the study area and overlapping layers, it allows to study the terrain where the object of study using contours, slopes, drainages natural and georeferencing.

Regard to the properties mentioned GIS, it becomes the ideal tool for managing mitigation of cultural heritage, especially in interactive maps that can be updated at any time and fulfill the mission to synthesize a series of data and have easy interpretation.

3. Methodology

Based on the second tool developed by (Díaz Fuentes, 2015), the aim is to make a hazard map with 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, and considering the greatest magnitude and intensity of each of the threats based on historical information (Laterza et. al, 2016).

The procedure proposed by Diaz is 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 (Laterza et. al, 2016). In Fig. 2 the reported diagram shows the division of the threats into three main groups: natural hazards of occasional action; threats of physical nature; and man-made and chemical hazards. Information references are also shown in each case (Díaz Fuentes, 2015).

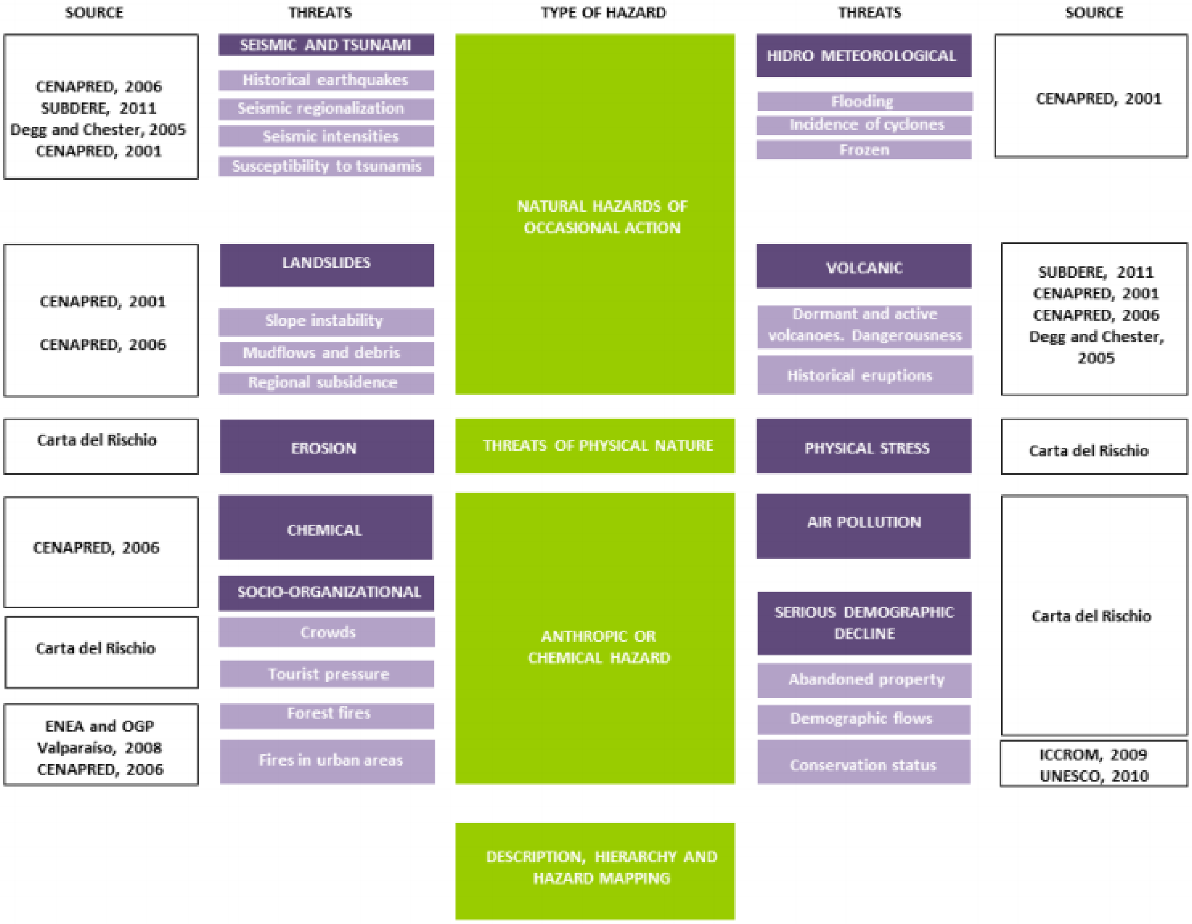


Fig. 2. Description, hierarchy and hazard mapping proposed by Díaz.

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 (Laterza et al, 2016).

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°C) 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 (Laterza et al, 2016).

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 (Laterza et al, 2016).

3.1 Prioritization of threats

The hazard map is a representation of known extreme events against what needs to be protected and the measures to be taken. These scenarios depend on the specific conditions of each site, both by the characteristics of phenomena as the vulnerability of buildings and their location

For hazard maps it is considered the worst case scenario as a backdrop, and identify areas where for a given intensity phenomenon, the consequences of damage to the cultural heritage property are no damage/ no hazard, gradual or catastrophic (Díaz Fuentes, 2015). Every parameter has a score based on the influence of the threat, as a site effect, in the seismic behavior of the building (Table 1) (Laterza et al, 2016).

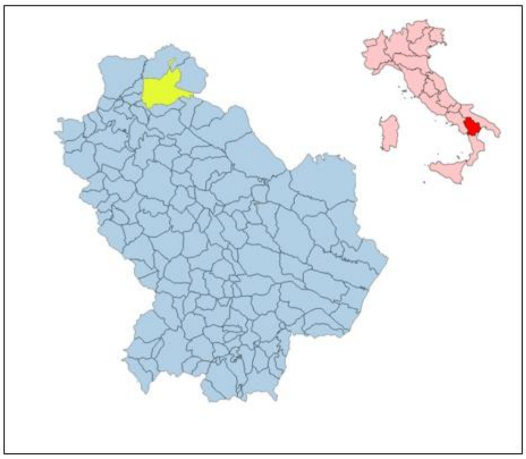
Table 1- Description of scenarios and prioritization of threats depending on the severity of damage and their score of influence.

Parameters		Severity of damage		
		No damage/No hazard	Low or gradual	Catastrophic
Sporadic events	Seismic threat - 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
	Chemical/ Forest Fire	0	0.02	0.05
	Socio-organizational	0	0.01	0.025
	Serious demographic decline: Lack of maintenance	0	0.01	0.025

4. Case study

To illustrate the use of the methodology of prioritization of threats of cultural heritage proposed by Diaz, it has made the analysis of threats that could affect the Aragonese Castle of Venosa (Fig. 3a) (Basilicata discover, 2016), located in the town of Venosa, Basilicata (Italy) (Fig. 3b).

(a)



(b)

Figure 3- (a) Aragon's Castle of Venosa. (b) Location of Venosa in Italy

The Venosa's castle was built in 1470 with the aim to protect the city from enemy attacks, it is strategically located on southern edge on the urban area, in a place where it was possible to watch the road that connected Venosa with the city of Taranto. The castle has a square shape with four towers with circular section (fig. 4), over time underwent changes in the structure and use, being military structure, jail, school, feudal house, cellar area, state offices and currently serves as a museum archaeological and historic. (Ministerio per i Beni e le attività culturali, 2003).

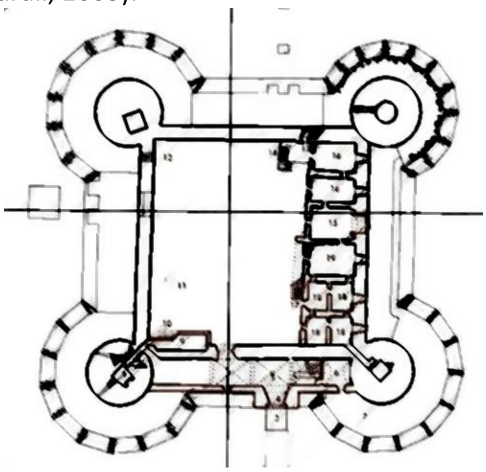


Figure 4- Venosa's castle plant

The stylistic and structural features of the castle are similar to those built in the fifteenth century and in particular have resemblance to the castle "*Castelnuovo*" of Naples, including: towers of circular section, foundations with embankment form dug into the rock, walls between the towers with a thickness of about 3 meters, body building complex on the ground level and in the space between the west tower and north tower under the ground level, cisterns of the Roman period (Fig 5) (Ministerio per i Beni e le attività culturali, 2003), the main material of the structure is calcarenite. The castle at the beginning had the entrance with an airlift in the south-east side, being changed to the current in the early seventeenth century (Direzione regionale per i beni culturali e paesaggistici della Basilicata, 2013).

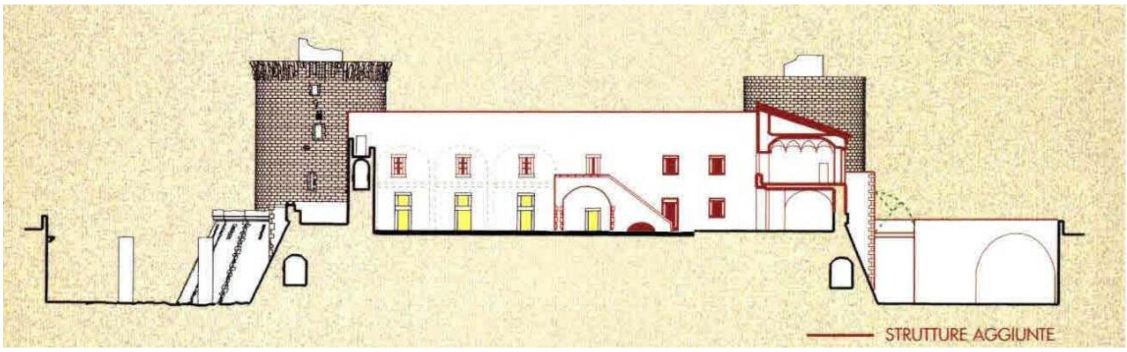


Figure 5- Venosa's castle profile

The castle is well preserved, especially because of the restoration work carried out in the decade of the 80, of the four towers, the west tower is the best preserved both internally and externally (fig 6a), retains most of its battlements, has a height of 22 meters and a diameter of 14 meters of section. The north tower is in good condition but without the presence of the battlements. The South and east towers are not as well preserved, especially the East tower, which is incomplete, where is possible seeing the lack of tuff on the walls (fig 6b) (Direzione regionale per i beni culturali e paesaggistici della Basilicata, 2013).

(a) (b)

Figure 6- (a) west tower of Venosa's castle- (b) East Tower of Venosa's castle.

4.1 Seismic threat

Venosa's territory is classified as seismic hazard 2, with a median seismic hazard, which means that might happen major earthquakes. The maximum expected acceleration for an earthquake in the territory of Venosa is <0.25g. Historically, the earthquake with more impact on Venosa was happened in Melfi in the year 1851, which had an intensity of X-XI Mercalli scale (Presidenza del Consigio dei Ministri, Dipartamento della protezione civile, 2015). An important fact to highlight is that there have been 17 seismic events over the last hundred years in the region of Basilicata. Despite the number of earthquakes in the region, the castle is preserved in very good condition, its main losses are reflected in the battlements and loss of material on the towers, and this shows the good seismic behavior of the structure.

4.2 Landslide or rock fracture

Throughout the territory of Venosa, are identified 14 points of constant landslides, classified according to their risk level, being high, very high and potential. These areas are located on the perimeter of Venosa, how the city is at a higher elevation, the landslides does not affect urban areas, however, it creates a risk to nearby buildings, as the collapse of the structures. (Martino & Gioia, 2012). Venosa's Castle is close to a very high risk area, although it has not generated damage on the heritage asset, however the landslide phenomena must be analyzed in depth and check the level of risk that would generate over the castle.

4.3 Erosion

Erosion as a continuous process represents a long-term threat to the structure, this is directly related to the direction and wind speed, as well as annual rainfall in the area. Periods of rain in Venosa occur especially during the fall and winter seasons, and have an annual average of 780mm. On the other hand, the average wind speed is 5m / s (Comune di Venosa, 2012).

The erosion process leads to deterioration of the building material, especially in the case of the castle of Venosa, which is tuff and has a high porosity.

4.4 Physical stress

Physical stress on the structure is given by environmental factors, especially temperature changes, which lead to internal stresses of the material with the passage of time they weaken the structure. In the case of Venosa, temperatures show a variation in the year of -3 ° C to 27 ° C in winter and summer respectively (Comune di Venosa, 2012). This threat, together with erosion may reflect a slow but steady process of degradation of rock and mortar of the building, leading to a weakening of structure, making it vulnerable to the seismic threat.

4.5 Air pollution

Venosa has no industrial area and sources of large volumes of CO_2 emissions (Comune di Venosa, 2012), therefore, this type of threat does not exist for the castle.

4.6 Chemical/forest fire

Although the city does not have a properly defined industrial area, it has a risk scenario of a major accident and identified as B. GLP srl plant, which is engaged in "reservoir for the storage and distribution of liquefied petroleum gas (LPG) in bulk and bottle, "which are typically classified as flammable substances, hazardous considerably for the community. Event of an impact of harmful type, areas to 80 meters from the plant would suffer damage insurance, areas to 150 meters form the plant would be considered moderate damage and areas to 200 meters from the plant would only care areas (Comune di Venosa, 2012). Venosa Castle is 200 meters from the plant, so there is the threat that if a fire occurs. However, the plant has adequate security measures and no historical records of explosions.

On other hand, the forest fire risk is possible due to the short distance that there is between the castle and "*Valle del reale*" which is the forest area nearest to the cultural property, and the last years it has had little fires in the forest with low level of hazard to Venosa (Comune di Venosa, 2012).

4.7 Socio-organizational

The territory of Venosa has low rates of crime or social disorder (Comune di Venosa, 2012), which means that this threat does not exist for the castle of Venosa.

4.8 Serious demographic decline: Lack of maintenance

There is no this threat in the territory of Venosa.

The threat analysis methodology was applied in Venosa and its affectations on the Aragon's castle, the results were summarized in Table 2 with their score and then represented on a map (see Figure 6).

Table 2- Prioritation of the hazard of the Castle of Venosa

Parameters		Severity of damage		
		No damage/No hazard	Low or gradual	Catastrophic
Sporadic events	Seismic threat - Maximum Mercalli intensity			0.40
	Landslide or rock fracture		0.15	
Continuous processes	Erosion		0.05	
	Physical stress		0.05	
	Air pollution	0		
	Chemical/ Forest Fire			0.05
	Socio-organizational	0		
	Serious demographic decline: Lack of maintenance	0		

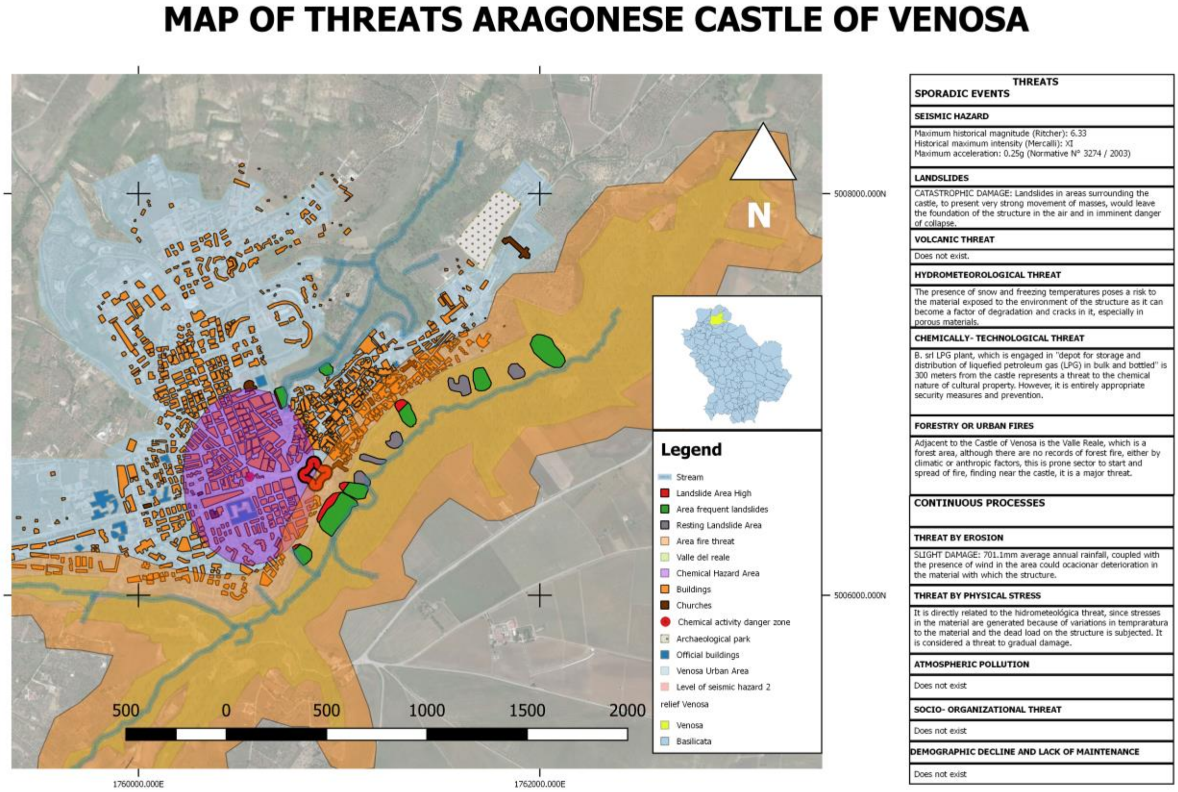


Figure 7- Hazard Map of Castle of Venosa.

Such as noted in Table 2 and Figure 7, the bigger threats to the castle of Venosa are seismic nature, landslides, chemical/forest fire, erosion and physical stress due of continuous processes

The classification methodology threats of cultural heritage was based on historical events and on qualitative and quantitative criteria. The methodology applied in this case, shows itself such as a simple tool of threat analysis to the cultural heritage, allowing to be used in countries which has not the resources to developing a deep work with techniques more detailed.

On other hand, the calcarenites of the structure are affected by physical, chemical and biological degradation phenomena, due to the porosity of the materal, allowing the entry into the materials of different agents present in the exposure environment (Bernardo & Guida, 2015). In the castle case of venosa, there's not aggressive agents, but there are physical degradation phenomenon due to continuous processes such as rains and wind.

In the structure is possible to see presence of grass on the walls of the castle that with the action of different species of bacteria may cause biological degradation phenomena and in consequence, the physical loss of material, which leads to the loss of historic and cultural value of the architectural or decorative heritage. Moreover, it affects the mechanical capacity of the walls and it increases the seismic vulnerability. The situation can be seen in the east tower, which has had loss of material, allowing the discontinuity on the wall of the tower.

5. Conclusions

The hazard maps are key tools in the risk management of cultural heritage. They may be implemented in a GIS approach for developing smart maps that can be updated at any time.

The quantitative and qualitative analysis of all threats affecting the architectural heritage represents the first step in the vulnerability analyses. In the case of Venosa Castle the identified threats are earthquake, chemical attack, fire and degradation in the material. Starting from them, in the future vulnerability analyses at simplified or at more refined level will be carried out in order to define a priority of interventions and to define the most suitable ones. For example, according to the considered case study, since there is the need of reducing the interventions invasiveness, innovative materials will be considered for mortar repointing of masonry. For example, the application of lime-based products with Nano-particulate additions enabling also the erosion protection and physical stress will be evaluated.

Acknowledgements

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). ELARCH project: Reference number 552129-EM-1-2014-1-IT-ERA MUNDUS-EMA21 funded with support of the European Commission. This document reflects the view only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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