RISK ASSESSMENT AND PREVENTION PRIORITIES IN CULTURAL HERITAGE PRESERVATION

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Introduction

Since the early days of earthquake engineering and up to nearly a decade ago, seismic assessment of existing constructions has relied on deterministic methods providing unrealistic and misleading information about their safety. In the last decade a new culture of structural safety was accepted acknowledging uncertainty and recognizing the possibility of failure. The construction is viewed as a system with its life cycle, the seismic performance of the entire construction and of its single elements are considered through multiple performance targets including economical and operability aspects. Given the inherent uncertainties in seismic input, construction modelling, and loss estimation, the assessment procedures have to incorporate probabilistic methodologies.

Concept and objective

(1) Earthquakes are one of the principal causes of cultural heritage losses (e.g. L'Aquila in 2009).

(2) Resources for safeguard and valorisation are very limited, tools for resource rational planning are lacking while tools for priority assessment are inadequate.

PRObabilistic performance-based methodology for seismic risk assessment of **CULT**ural heritage

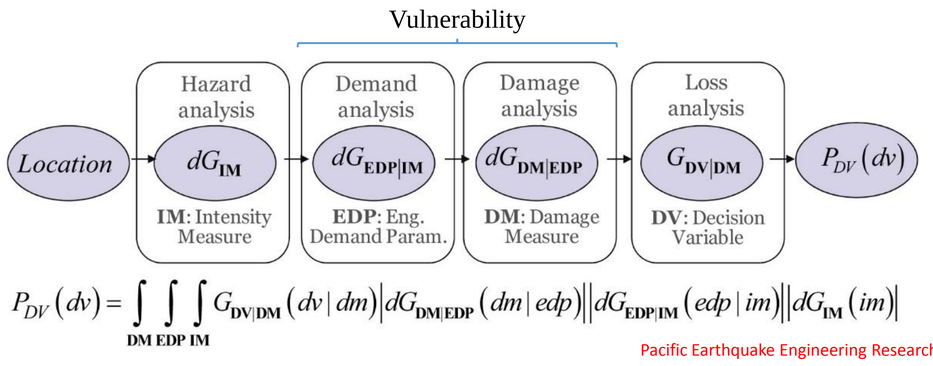
PROCULT

Advancements on the evaluation of the seismic risk of cultural heritage in order to provide a scientifically supported definition of priorities to be used in decision-making processes

Seismic risk

Probability of a **specified amount of loss** in a **specified time interval** as a consequence of seismic events

PEER general framework



Pacific Earthquake Engineering Research Centre

Each aspect is studied and solved in a rigorous and consistent interdependent manner, after that separate conclusions are reconnected in a probabilistic framework.

- Geology and seismology
- Structural engineering
- Mathematical modelling
- Survey
- Consolidation
- Art and architecture history

PROCULT aims at developing risk analysis in a context more rationally related to the nature of cultural heritage by investigation of the following topics:

(1) hazard evaluation considering the influence of previous recent events, moving from time-independent Poisson probabilistic models toward time-dependent Markovian models;

(2) evolution of material and structural properties (ageing) in the definition of seismic vulnerability and seismic fragility that become time-dependent allowing a more rational planning of maintenance actions;

(3) analysis of the influence of time on the value and decision variables, considering the time-dependent issues involved in contingent evaluation;

(4) definition of suitable survey procedures for complex geometries, including the relations between form, construction sequences, vulnerability;

(5) assessment of the potential loss estimation by considering cultural heritage material and immaterial values.

Geological knowledge and seismic hazard

Deterministic Seismic Hazard Assessment (prevalent up to 1970s-80s):

- discrete, single-valued events or model of ground motion based on the maximum expected earthquake at the site;
- no information on the likelihood of the earthquake, on the level of shaking expected during the structure life-time, and on the effect of uncertainties.

Probabilistic Seismic Hazard Assessment (last 20-30 years):

- uncertainties in the size, location and rate of occurrence of earthquakes and in the variation of ground motion characteristics, are identified, quantified and combined in a rational manner;
- multidisciplinary probabilistic seismic hazard models integrating geological, seismological, and geophysical information.

Results deriving from these approaches will be used in order to compare differences for the final specific objective of PROCULT.

Construction knowledge and vulnerability assessment

PROCULT investigates the following issues relevant to the evaluation of probabilistic distribution of damages as a consequence of seismic events with a selected intensity:

- definition of specific engineering demand parameters for cultural heritage structures;
- definition of specific damage measures for architectonic details, frescos, mosaics, museum contents (in addition to those adopted for usual constructions);
- evaluation of relations between intensity measure and probability of over-passing a particular damage measure by means of numerical and analytical models.

Value estimation and loss analysis

Loss analyses based on estimate of costs related to construction strengthening and maintenance is completely inadequate for heritage structures and should involve the evaluation of its symbolic and social value together with the relations with cultural identity of communities, quality of life of citizens, tourism and cultural activities.
PROCULT aims at investigating the possibility of exploiting studies developed recently (e.g. Contingent Valuation used for environmental heritage or libraries) and is oriented to provide original contributions on the following aspects:

(1) modalities to incorporate value assessment methodologies in a probabilistic-based decision-making process;

(2) definition of the relationships between physical (vulnerable) components of the constructions and global value;

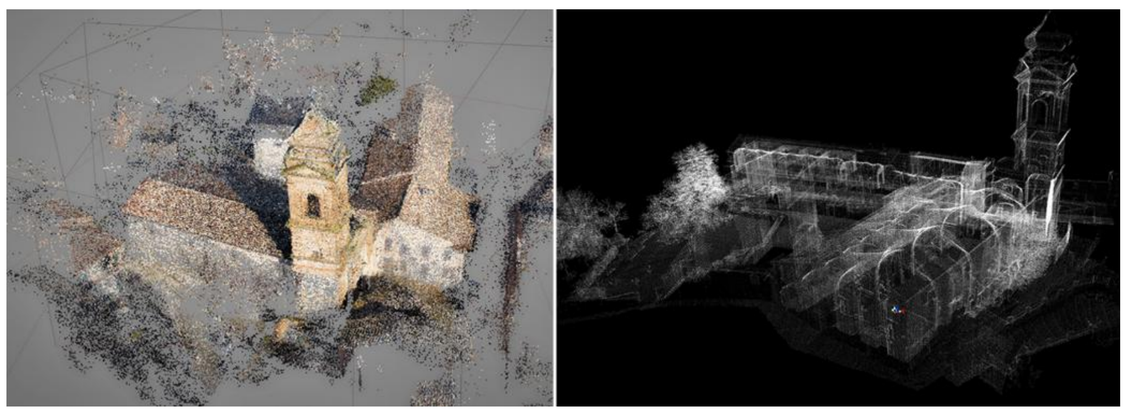
(3) review of existing survey techniques and choice of the most suitable for value assessment.

Case study

The selected case study is the Convent of San Francesco in the highest part of the town of Monterubbiano (Marche, Italy). The complex was subjected to several functional changes and has undergone a number of substantial modifications.

1247	foundation of the church of San Francesco with its cloister
1428	demolition of the roof trusses replaced by the current coverage with brick masonry vaults
Early XVII	the orientation was inverted placing an entrance on the side of the apse and the altar on the ancient façade
1728	seven altars with numerous works of art
Late XVIII	the original bell tower was demolished and replaced with the current one
1997	Umbria-Marche earthquake damages the complex
2007	last restoration

The complex is currently used as an auditorium for exhibitions and conventions and encompass an Archaeological Museum, a library with about 45,000 volumes, and the Environmental Education Center “Janus”. It consists of many rooms with a very articulated spatial organization.
Point cloud-based survey was carried out to highlight all the traces and the architectural stratifications occurred over time. 3D data were acquired by a time-of-flight (TOF) laser scanner (83 TOF stations) and using an unnamed aerial vehicle (UAV) equipped with an optical digital system camera (93 photographs) in order to survey some external walls difficult to reach with the laser scanner, the multilevel roof, as well as the richly moulded bell tower. The various points clouds achieved with the different technologies were processed, oriented, scaled, optimized and registered to obtain a high density point cloud-based model. High poly and low poly 3D models were generated for different purposes such as the risk assessment analyses (FEM analysis), the photorealistic representations of the current state as well as the historical documentation of the complex.



High density point cloud-based models: point clouds acquired with UAV equipped with an optical digital system camera and point clouds acquired with TOF laser scanner