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A novel procedure for exposure and vulnerability of Cultural Heritage at landslide risk.

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A rigorous landslide risk analysis and assessment require, together with definitions of typology of phenomena potentially destructive, characterization of exposed element involved in the landslide and their relatives vulnerability conditions. In the scientific literature, vulnerability in landslide risk analysis, has still not exhaustively developed due, for instance, to the objective complexity for the parameterisation of indicators and the necessity to solve this topic under a multi-disciplinary approach (e.g. Socioeconomic vulnerability, Structural vulnerability, Sustenance vulnerability, Setting vulnerability). Scope of the work is to propose a first approach of landslide vulnerability assessment addressed to archaeological sites, starting from vulnerability assessment experiences, consolidated in the field of seismic risk evaluation, and adapted to hydraulic and geomorphological risk assessment. The present work is mainly focused to synthesise an innovative approach on the exposure and vulnerability assessment analysis developed in the last decade by ENEA and Consorzio Civita in archaeological sites and historical urban areas, in Italy and other countries. The methodology is subdivided in two different operational phases: the former is addressed to the definition of typology of exposed elements, the latter to definition of vulnerability. The analysis of the exposed archaeological elements and the consequent landslide vulnerability are a fundamental task for a rigorous landslide risk assessment and management. Studies on cultural heritage at risk have stressed that a merely economical appraisal of the "value" is inadequate and inappropriate for a typical cost/benefit analysis. An "exposition index", referred mainly to historical, cultural, religious and artistic parameters of the exposed elements is to be preferred though considering the economic parameter in terms of direct income from i.e. tourist exploitation. The application has been devel-

oped through the implementation of a GIS-based approach, data survey by means of an innovative catalogue focused on the historical and archaeological vulnerability indicators and, finally, data spatial analysis. The vulnerability analysis has been performed with the direct investigation of buildings and structural typologies of the exposed elements as well as the rigorous survey of damage related to the localisation of the elements in potential landslide areas (i.e. uphill, downhill, inside the landslide body). The compilation of the catalogue allows to verify structural conditions of the exposed elements and elaborate and define fragility and vulnerability curves and functions linking the three fundamental parameters of vulnerability definition: (i) the landslide intensity for any structural typology of exposed elements, (ii) their structural characteristics and (iii) potential damage. The analysis of effects of landslide activity on different exposed elements has been implemented starting from the concept of typology and landslide classification such as: localization of the exposed elements in potentially active or landslide prone areas, landslide intensity vs. of location of the element at risk and the prevalent structural characteristics of the exposed element. Each landslide typology has a distinct influence on the choice of parameters for the analysis of vulnerability. For instance, velocity, impact energy, run-out are fundamental elements in assessing intensity and potential effects of fast-moving landslides on damage analysis of exposed elements whereas failure depth, volume of unstable mass and retrogressive activities are fundamental elements to be considered in slow-moving landslides. The research has provided the definition of diagrams that correlate vulnerability parameters defining fragility curves plotted and interpolated in classes of vulnerability. The GIS analysis of data, as vector layers, has permitted to define maps referred to an Exposition Index (IE) and Vulnerability Index (IV). Finally, this novel methodology is the result of a multi-disciplinary approach applied to Earth Science disciplines and represents a first step for a rigorous landslide risk analysis applied to cultural heritage.