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Review

Traditional earthquake resistant techniques for vernacular architecture and local seismic cultures: A literature review

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ABSTRACT

Specific architectural elements can be identified in constructions located in regions frequently exposed to earthquakes. These earthquake resistant features were developed empirically by local communities to protect their built-up environment. Research in these traditional earthquake resistant practices, resulting from a local seismic culture, is a relevant and positive approach, since it focuses on the strengths of a system rather than on its weaknesses. Its integration into current vernacular building practices can help to preserve and retrofit surviving in-use examples without prejudice to their identity. This paper presents an overview of the most common techniques traditionally used around the world, based on literature review. Additionally, it identifies the use of these techniques in the Portuguese vernacular heritage in order to contribute for the awareness and strength of the local seismic culture in Portugal.

1. Introduction

Vernacular architecture located in earthquake prone areas is particularly vulnerable because of the generalized use of poor materials, the scarcity of resources in poor communities, and the poor maintenance, associated at times with lack of a good construction. Nevertheless, due to the long-term exposure to earthquake hazard, local communities are eventually forced to adapt to this risk and protect their built-up environment. People can either undertake preventive measures, repairing and refurbishing their personal properties in order to minimize future losses in the following earthquakes, or they can respond to earthquakes just in the immediate aftermath of the event, with no future orientation, developing a reactive response behavior [1]. In any case, traditional seismic resistant construction techniques arise from this need to repair earthquake damage to both personal and public buildings. These efforts made by local populations as a reaction to earthquakes gave rise to the development of a local seismic culture, which is a key element for the preservation of cultural identity and vernacular construction practices. The use of technological and standardized materials in a globalized world created a tendency to unify the way of building, jeopardizing local building cultures and vernacular architecture. For this reason, the valorization and preservation of the vernacular heritage is crucial, not only as a witness of the past, but also as a key factor for local development, boosting local economies [2,3].

Ferruccio Ferrigni, Centro Universitatio Europeo per i Beni Culturali (CUEBC), recognized the existence of local seismic cultures and carried out the first research project aimed at reducing the seismic vulnerability of the traditional housing stock based on the rediscovery and development of local know-how [4,5]. Local seismic cultures and traditional earthquake resistant techniques have been identified in many regions around the world frequently exposed to earthquakes, such as Italy [6], Greece [7], Turkey [8], Algeria [9], Iran [10], India [11], Nepal [12], Japan [13], Haiti [14], and Colombia [15]. Other organizations such as CRAterre have developed risk management programs including the construction of traditional seismic resistant housing in El Salvador and the development of guidelines for reconstruction based on the local seismic resistant building culture in Kashmir [16]. The World Housing Encyclopedia [17] is another project of the Earthquake engineering research institute (EERI) and the International association for earthquake engineering (IAEE) that collects existing construction practices in earthquake regions, with a focus on vernacular building typologies. Its main objectives are to understand the seismic vulnerability of these construction systems and the reasons for their good or poor seismic performance, as well as to provide recommendations for strengthening [18,19].

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Research in vernacular architecture has predominantly been focused on building typologies and spatial organization, while research in seismic strengthening solutions has for a long time been addressing monumental architecture instead of the vernacular heritage, which has traditionally been ignored and underestimated. However, in the last years, there has been a growing interest on the experimental characterization of the seismic behavior of representative vernacular construction systems [20–23], as well as on seismic strengthening solutions for vernacular constructions based on modern techniques and materials [24–26]. Still, little research has focused on traditional strengthening solutions emerging from vernacular architecture [27]. Therefore, the present paper addresses this critical gap in knowledge regarding vernacular architecture earthquake preparedness and the most common measures adopted by local communities to repair and restore their dwellings. For this purpose, this paper presents a comprehensive overview of earthquake resistant techniques and practices identified in regions frequently exposed to earthquakes based on a review of the literature, aiming in particular at a better understanding of their structural role.

It is considered that a better awareness of traditional earthquake resistant measures is important to protect and reduce the seismic vulnerability of the built vernacular heritage by encouraging local communities to recognize and readopt techniques emerging from a local seismic culture. Unfortunately, local communities are gradually abandoning the local seismic culture because they rely less and less on it [28]. Traditional construction techniques are being replaced with new modern techniques and technologies which enable structures to be erected quickly and cheaply, but not necessarily safely [29]. The overview presented in this paper on the local seismic culture and traditional earthquake resistant techniques is based on the research that has been developed under the framework of the research project "SEISMIC-V–vernacular seismic culture in Portugal" [30], which specifically focuses on the study of local seismic cultures and on the identification of adequate seismic retrofitting techniques for vernacular buildings in Portugal. Therefore, the paper also elaborates on the Portuguese context by indicating which techniques can also be recognized within Portuguese vernacular architecture, so that it can additionally contribute to the reflection on the existence of a local seismic culture in Portugal.

2. Basic concepts

2.1. Vernacular architecture and local seismic cultures

The object of this overview is the vernacular architectural heritage, which comprises dwellings and other buildings built by the people. Vernacular buildings are usually owner or community built. They are not designed by specialists but, on the contrary, are part of a process that involves many people over many generations and are based on empirical knowledge. This is why vernacular architecture is often called communal, popular or folk architecture and even "architecture without architects" [31]. Following the same reasoning, vernacular architecture has often been defined as the opposite of high or monumental architecture. Still, vernacular is the most common term used by academics [32,33] and professionals [34].

Earthquakes striking cities and devastating communities have been reported since ancient times. However, in spite of the constant threat that earthquakes represent, far from abandoning these seismic prone regions, people have proven to be exceedingly attached to the places where they have always lived and have remained living under these dangerous circumstances. Consequently, it seems reasonable that people coexisting with earthquakes are forced to learn how to protect themselves from them and have developed preventive measures for earthquake mitigation. This is the origin of a local seismic culture. Considering that the built up environment is the most vulnerable element to earthquake forces and the major cause for the economic and human toll, most of the efforts have been dedicated to improve the seismic resistance of constructions, aiming at minimizing the earthquake catastrophic effects.

As part of the vernacular practice, local seismic cultures make use of locally available materials, skills and resources but, more importantly, they are culturally sensitive to the local building tradition and effective in resisting earthquakes. This type of knowledge derives from centuries of trial and error and generally uses low-level technology. However, it is frequently disregarded and rarely documented or scientifically explained. For this reason, research in hazard mitigation through vernacular building practices resulting from a local seismic culture is relevant.

The main factor that leads to the development of a seismic culture is earthquake hazard awareness, which is strictly correlated with the seismic hazard of the region or the probability of occurrence of an earthquake in a given area. In addition to the seismic hazard, the impact of the earthquake on the built-up environment is of great importance. In this way, methods and construction solutions proved as dangerous after an earthquake are either abandoned or modified, while reconstruction works will copy those construction techniques that have withstood the event, as a sort of natural selection.

There is a close correlation between the development of seismic resistant building practices and the earthquake frequency [7]. Earthquakes must be frequent in a region so the people can remember the seismic behavior of the empirically devised techniques. At least one important earthquake during the life period of a generation is needed to keep the local seismic culture level high, resulting in a "culture of prevention", and enhancing the quality of aseismic construction (Fig. 1). If earthquakes are not frequent and there are long periods of time between the seismic events, larger than the average generation life time, the function of different techniques implemented after an earthquake will be forgotten and gradually abandoned, developing a "culture of repairs". This loss of the collective memory of past events eventually leads to the abandonment and erosion of seismic cultures.

The development of a seismic culture is not only related with the frequency of the earthquakes but also with their intensity. As an example, Portugal has a moderate seismicity characterized by small events, but several devastating earthquakes have sporadically struck the country throughout its history. This has led to the development of important reactive responses in which seismic resistant constructions were devised and implemented after earthquakes, such as the well-known "*Pombalino*" buildings after the 1755 Lisbon earthquake. However, due to a progressive loss of seismic awareness, "*Pombalino*" buildings were replaced by the "*Gaioleiro*" buildings, with a much worse construction quality and where the initially devised seismic resistant measures were neglected, increasing their vulnerability [35]. A similar example can be found in India, where the seismicity of some regions is also characterized by a relative high frequency of large earthquakes and low frequency of moderate earthquakes. According to Jain [36], this has led to the development of seismic resistant construction typologies, such as the "Assam-type" timber-frame houses developed after the 1897 Assam Earthquake. They showed an excellent performance in subsequent earthquakes but were again abandoned because of the lack of seismic concern.

2.2. Earthquake performance of vernacular constructions

The serious aftermaths of earthquakes, such as human fatalities, are caused mainly by the collapse of poorly constructed or unsafe buildings and other man-made structures. Therefore, the

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