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Earthen vernacular architecture in flood-prone areas: characteristics and typologies in the Ebro basin

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Topic: T1.1. Study and cataloguing of vernacular architecture

Abstract

Earthen architecture is one of Spain's longest-standing construction traditions, used from antiquity to the mid-twentieth century. Given its hygroscopic nature, earthen architecture is generally seen as barely resistant to water and as more associated with geographical areas with hot and dry climates. However, it is found in different places with different climate and geographical characteristics. In these surroundings, its survival over time has been ensured by a process of adaptation and modification producing architectural and constructive forms which reflect the identity of the geographical areas in question. One of the main risks to earthen architecture are floods, which have always represented a threat to this architectural heritage. The increased frequency and intensity of floods due to climate change have in turn gradually given rise to an increasing risk of disappearance for this architectural heritage. This paper aims to study the typologies and features of earthen vernacular architecture in flood-prone areas through the analysis of case studies in the Ebro basin. The study of earthen buildings in the area under study provides information on the most recurrent architectural features and vulnerabilities, as well as the inherent resistance which has enabled this earthen architectural heritage to survive. Moreover, a study of the pathologies and structural damage visible on buildings highlights those which are a direct consequence of the action of water and can potentially affect structural behaviour during a flood. Aiming to establish conservation strategies for earthen architectural heritage the data collected are analysed using a qualitative vulnerability assessment methodology, establishing the degree of influence of individual characteristics on the response of earthen structures to floods.

Keywords: *floods; vulnerability; conservation strategies; climate change.*

1. Introduction

Vernacular architecture or architecture "without architects", as termed by Rudofsky (1964), can be defined as a form of building connected closely to territory, the geographical space in which it is located. This connection is apparent in the architectural type and the construction techniques. Architectural heritage in the territory of the Iberian Peninsula, which is extremely varied, is the result not only of geographical conditions but also of social and historical ones. Thus, vernacular architecture has developed thanks to the combination of several factors: geographical, climatic, historical and social. These factors have influenced the definition of the architectural type and the development of the construction techniques. Earthen architecture is one of the most widespread constructive traditions of the Iberian Peninsula and Earthen construction techniques, used since ancient times, continued until the first half of the twentieth century (De Hoz Onrubia et al., 2003). Despite the progressive abandonment of this constructive tradition, the energy crisis and climate change issues have prompted a renewed interest in earthen architecture. This in turn has encouraged extensive study and research, as well as publications and manuals on the topic (Jaquin, 2012; Maldonado Ramos & Vela Cossío, 2002; Warren, 1993). In addition, many authors have focused on the study of earthen architecture in the Iberian Peninsula (Gómez-Patrocinio et al., 2020; López Martínez, 1999; Camilla Mileto et al., 2019; Vegas et al., 2011) and on its conservation (Keefe, 2005; C. Mileto & Vegas, 2017; Warren, 1999). At present, climate change has had a major impact on the risks associated with the loss of architectural heritage, with a significant increase in the scale and frequency of natural risks such as floods (Bracchi et al., 2020; Díez-Herrero et al., 2008; Eguibar et al., 2021; Huntington, 2006; Lastrada et al., 2020). As a result, the concepts of the vulnerability of architectural heritage and risk prevention and mitigation are of paramount importance (Canivell et al., 2020; Figueiredo et al., 2021; Ortiz et al., 2014). Flooding is one of the greatest threats to architectural heritage, causing irreversible damage and, in some cases, the collapse of structures (Drdácký, 2010; Herle et al., 2010; Mebarki et al., 2012). Although earthen architecture is generally considered more vulnerable to the consequences of flooding given its hygroscopic nature (Beckett et al., 2018, 2020; Gerard et al., 2015) various earthen buildings, both monumental and vernacular, have been found in areas exposed to flooding in the Iberian Peninsula (C. Mileto et al., 2021; Trizio et al., 2020, 2021). However, these traditional buildings are disappearing due to social and other external factors, such as the erosion and land consumption caused by flooding, even in areas which had previously been dry. This paper aims to analyse and catalogue vernacular earthen buildings located in flood-prone urban areas in order to identify their most recurrent formal and constructive characteristics. For this purpose, the Ebro valley has been selected as an appropriate case study area since it is a territory with extensive earthen architecture (Villacampa Crespo, 2018). Moreover, a component-based methodology is used to assess flood vulnerability in order to establish conservation strategies and guidelines for the protection of earthen vernacular architecture.

1.1. Territorial context

The study area of this paper is the basin of the river Ebro, where there are urban centres at high risk of flooding in the flood plain (ANEXO I Municipios y Núcleos de Población Situados En Zona A de Alto Riesgo, a Efectos de Emergencia Para Poblaciones, Incluidos En El Anexo XII (Tabla 12), Del Decreto 201/2019, de 8 de Octubre, Del Gobierno de Aragón., 2019). The Ebro is one of the rivers of the Mediterranean basin of the Iberian Peninsula (Fig. 1).

Fig. 1. Basins and flood-prone areas of the Iberian Peninsula. Legend: 1. Cantabrian Basin; 2. Mediterranean Basin; 3. Atlantic Basin (Source: Authors, 2021).

In its lower-middle course, the Ebro River causes serious prolonged floods exceeding 3000 m^3/s. These floods are due to long-lasting frontal precipitation or snow melting pre-eminently during the summer months (Camarasa Belmonte, 2002). The case studies selected for analysis are located in the town of Torres de Berellen (Fig. 2), 20 km from Zaragoza, the capital of the Autonomous Community of Aragón. The urbanised territory of the municipality covers an area of 53.8 km^2. During the periods of major river flooding the town is reached by water because of the bottleneck that the river causes as it reaches the urban area nearby. In addition, as it is impossible to expand the evacuation section the water flow velocity increases, triggering important erosion issues in the area (Gobierno de Aragón, 2005).

Fig. 2. Map of the territorial context of Torres de Berellen.

2. Methodology

The analysis carried out in this study is based on a methodology which catalogues earthen architecture and assesses flood vulnerability in flood-prone areas. The study is divided into three fundamental phases: data collection, analysis and evaluation. The data collection phase was preceded by a preliminary phase in which the most relevant areas were selected for study. This selection was made by superimposing the map of the distribution of earthen architecture in the Iberian Peninsula (SOS-Tierra Project, https://sostierra.blogs.upv.es/) onto that of the flood-prone areas obtained from the SNCZI (National System for Cartography of Flood-prone Areas) for Spain and the Portuguese Environmental Agency for Portugal. The strategic use of maps as tools for vulnerability assessment made it possible to establish the basis for preliminary study and flood vulnerability and risk assessment (Hervas & Bobrowsky, 2009; Wang, 2015). In addition, this superimposition of maps resulted in a map showing the flood exposure of architecture in the Iberian Peninsula (Fig. 3), a tool essential to the preliminary phase. Thanks to this map the most common earthen construction techniques within the areas most at risk from flooding were identified. As Figure 3 shows, there is a high concentration of adobe buildings in the Ebro basin.

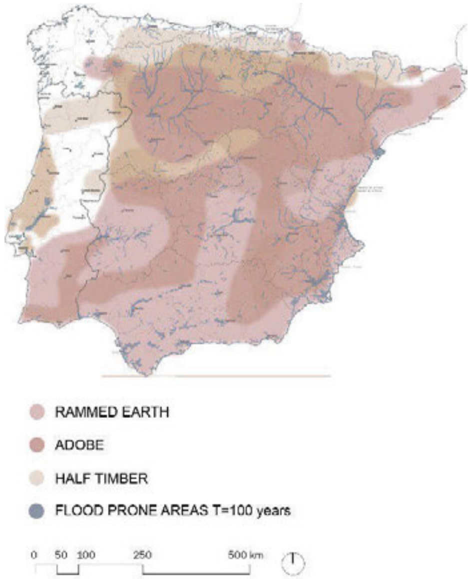

Fig. 3. Flood exposure map of earthen architecture in the Iberian Peninsula (Source: Authors, 2021).

As a result, the town of Torres de Berellen, with a high proportion of adobe buildings, was selected as a highly suitable case study. Subsequently, fieldwork was used to obtain information on the characteristics of the earthen buildings, which was then organised into synoptic data collection forms. These contain all the building characteristics that are essential to this analysis, divided into three categories: environmental, morphological and constructive. The characteristics identified in the data collection forms have been used as susceptibility parameters for assessing the flood vulnerability of earthen architecture. In order to simplify the analysis, the number of susceptibility, urban typology, number of floors, rendering and additional protection (Fig. 4).

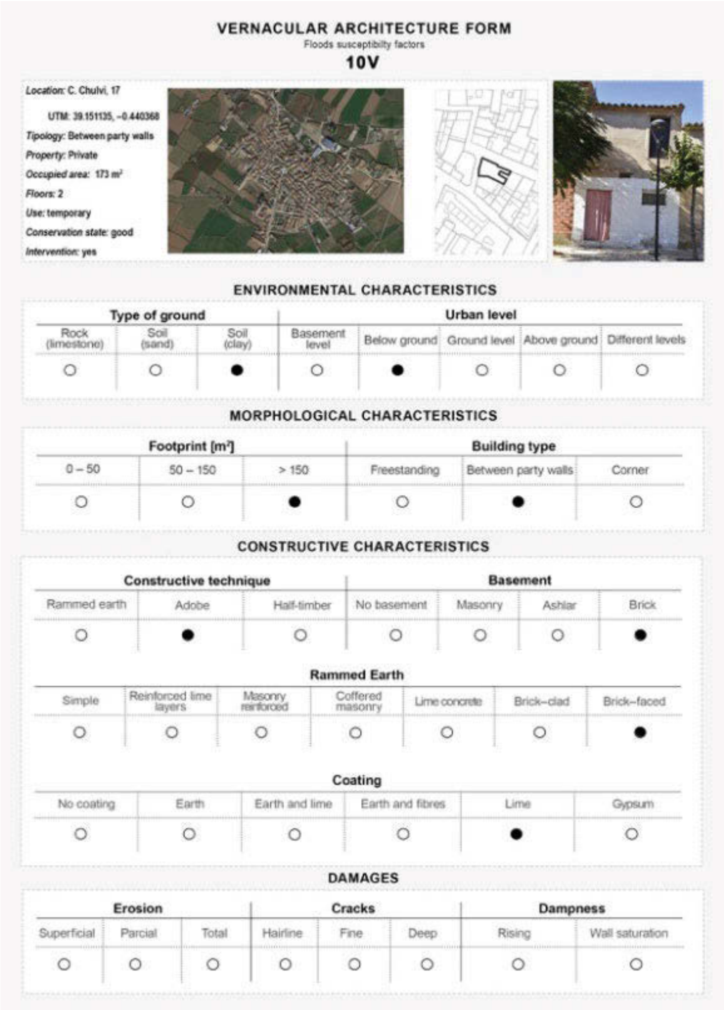

Fig. 4. Data collection form (Source: Authors, 2021).

Each characteristic was assigned a susceptibility value between 1 and 5, weighted by a reduction factor calculated using the Delphi method (Gordon, 1994; C. Mileto et al., 2021). In addition, the state of conservation of the buildings was taken into account in the vulnerability assessment, by including parameters which represent pathologies and structural damage affecting the buildings that could influence flood resistance.

3. Results

In the first phase of the work, the fieldwork, 38 earthen buildings in Torres de Berellen were identified. All case studies are built in adobe, a construction technique which continued in use until the first half of the twentieth century. An initial analysis of the buildings and the quality of the walls highlights some fundamental characteristics of their architectural type and construction techniques. The buildings are between 3 and 8 metres high, and have 1 to 3 floors. The ground floor is generally used as storage or a garage while the upper floors are used as dwellings. From a constructive and structural perspective, the building structures incorporate load-bearing walls 40 to 60 cm deep. The walls are made of adobe blocks measuring 17.5x7.5 cm on average with 2 cm mortar joints. The corners are reinforced with bricks in order to ensure greater structural stability. Moreover, the wall plinths are made of bricks or concrete blocks which have been added in some cases to fill gaps, while in other cases the entire plinth is built with concrete blocks. The height of the plinth varies from 60 cm to 110 cm. In many cases, the buildings are in an advanced state of decay. Different types of damage identified include cracks, rising damp and saturation of the walls (Fig. 5).

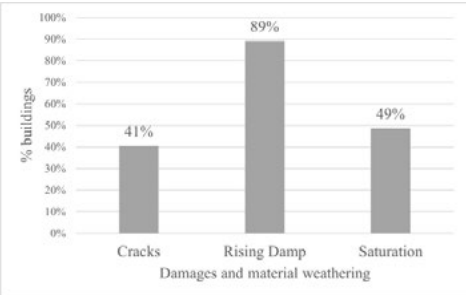

Fig. 5. Percentage of buildings with damages and material weathering.

Differential settlements and rotations caused by the long-term effects of flooding can lead to the formation of vertical cracks. Indeed, the presence of water in the foundation soil favours erosion and results in differential settlements. In addition, adobe masonry does not use transversal connections such as ties to prevent the independent rotation of the parts or cracks worsening. According to surveys on the state of conservation of buildings a high percentage of the case studies analysed shows rising damp. While the presence of moisture in the walls could trigger severe damage mechanisms this type of degradation is not usually included in flood damage analyses (Kelman & Spence, 2004). However, it was considered appropriate for this analysis as it is detrimental to the overall resistance of the walls. Siedel (2010) explained that floods occur in a short time with wide intervals between events. As a result, the saturation of materials, which modifies their characteristics and damages architectural components, takes place in a short period. The effects of excessive saturation may also include the loss of material, especially in the plinth, as found in some case studies (Fig. 6). This material degradation is mainly due to the characteristics of non-stabilised earth, which has a strong hygroscopic nature.

Fig. 6. Vernacular adobe building with visible erosion.

After carrying out the morphological and degradation surveys, the flood vulnerability of each case study was assessed. The vulnerability index values obtained ranged between 1.5 and 3 on a scale of 1 to 5. The vulnerability indexes of the buildings assessed are in a range of low and medium values, as shown in Fig. 7.

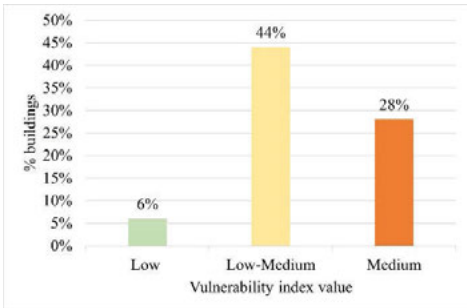

Fig. 7. Vulnerability index results. Legend: Low (<2); Low-Medium (<3); Medium (<4).

Analysis of the data obtained shows that despite the presence of various forms of degradation, buildings are not highly vulnerable to flooding. However, as the buildings are exposed to floods, appropriate strategies are necessary to mitigate the risk and the consequent effects. Therefore, the study of structural and non-structural measures is considered necessary (D'Ayala et al., 2020). The design of emergency plans is considered a key measure for preventing further damage and reducing risks. Such plans could reduce the impact of flooding and prevent possible damage to historic structures. It is essential to establish criteria and guidelines for restoration and structural reinforcement¸ in addition to non-structural measures. A correct design of conservation actions, such as the interventions for reducing rising damp and wall saturation, as well as structural actions to reduce displacements and differential settlements, can prolong the useful life of traditional buildings, preserving their mechanical characteristics and strength without damaging their historical and traditional features.

4. Conclusions

The cultural heritage of traditional earthen architecture is the result of knowledge and techniques with roots in the history of its setting. At present, this heritage is in danger of disappearing due to certain risk factors, jeopardising its survival. Floods are a threat to traditional earthen architecture. In the Iberian Peninsula, the Ebro basin is a flood-prone area where floods have threatened earthen buildings on several occasions. From the morphological and constructive study, it can be concluded that the traditional constructions of the Ebro basin analysed in this paper are mostly made of adobe. Furthermore, the vulnerability assessment led to some conclusions. Firstly, the degradation issues identified decrease the resistance of buildings making it necessary to carry out structural reinforcement actions in order to reduce vulnerability. In fact, if risk is seen as the combination of exposure, vulnerability and probability of the event occurring, only vulnerability depends on the characteristics of the object exposed to risk. Therefore, to conserve heritage it is necessary to intervene not only on the buildings to be protected but also on the surrounding territory through prevention and risk mitigation plans. Vernacular architecture is particularly important as it creates a sense of belonging to places. It comes "from the place" (Loos, 1910), without effort or disfigurement of the landscape, and from careful observation and knowledge of the use of the territory by its inhabitants. Preserving vernacular architecture means preserving this ability to design while maintaining a strong awareness of the landscape.

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