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Original article

Natural disasters written in historical woods: Floods, a thunderbolt fire and an earthquake

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ABSTRACT

The present paper analyzes different types of natural disasters recorded in the woody elements from reconstruction or repair works in two World Heritage buildings (the Old Mint and the Cathedral) in Segovia (Central Spain). We employed architectural and historical documentation, along with archaeo-seismological analysis techniques in order to frame the events and processes. We analyzed several woody elements from the wooden deck of the Old Mint, including beams, planks and support blocks; and for the Cathedral roof the structural elements analyzed were tiebeams, raised aisles, rafter braces, common rafters and roof battens, as well as many planks and soulaces. For the dating, we combined two methodological approaches based upon dendrochronological techniques (dendroarchaeology and dendrogeomorphology) in an integrated study of the tree-rings series obtained. Furthermore, four wood samples (one from the Old Mint and three from the Cathedral) were dated by means of radiocarbon techniques. The results enable us to detect and corroborate the dates of at least two catastrophic flood events that affected the Old Mint (1695 and 1733). Additionally, we establish the unknown effects to date upon the Cathedral roof of the fire caused by the thunderbolt in 1614 and by the Lisbon earthquake in 1755. From the point of view of cultural heritage, these data are of great interest for the history of the reconstruction of the Old Mint and of the Cathedral of Segovia.

1. Introduction

Since almost a century ago [1,2], dendrochronology has been commonly employed to establish the age of trees, but it has also been used to date the wood elements of several manmade artefacts such as buildings, boats, furniture, painted panels and even musical instruments (see, among others [3–5]). The results of these studies have enabled the dating and chronological ordering of settlements and artistic styles of archaeological sites (dendroarchaeology [6,7]) and other modern manmade objects (see compilation for the Iberian Peninsula in [8]). Some of these datings have made significant contributions to historical and prehistorical studies because they allow dating to be performed at a one-year resolution as compared with the wider confidence intervals of other dating methods (radiocarbon, luminescence, . . .). Furthermore, dendrochronological studies are used to calibrate radiocarbon dating curves. Precise tree-ring dating of buildings is even possible, despite the absence of bark [9]. Additionally, dendrochronology can provide more detailed information about the provenance of the timber [4,10]. In summary, dendroarchaeology throws light upon interactions between humans and their natural environment in specific periods of time [8].

Furthermore, since the late 1960s, dendrochronology has been combined with geomorphological analyses in order to date and quantify the magnitude of natural disasters, such as floods, avalanches, landslides, rockfalls, volcanic eruptions, earthquakes, etc. This combination, known as dendrogeomorphology [11], has furthered our knowledge of the frequency of occurrence of these catastrophes in the past, thus enhancing their prevention. A brief compilation of the application of the dendrogeomorphology to natural hazards studies can be found in [12]. These studies usually date and quantify past natural disasters from disturbances and changes in tree-ring sequence and other external and internal evidence in living trees.

Nonetheless, these two approaches in the use of dendrochronological techniques have not been combined to date in an integrated

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study of natural disasters recorded by means of the tree-ring sequences of timber elements in human constructions. Only the previous studies by [13–16] have explored this interesting line of research.

Indeed, when the elements of buildings (i.e., roof) and other constructions (i.e., canals) made of wood were used after natural disasters or catastrophic events in reconstruction or repairs, dating of these timber elements suggests the occurrence of the natural disaster, as well as the date thereof.

This approach constitutes a highly original way of studying historical (and prehistorical) catastrophic events 'written in wood', because it does not use disturbances in the tree-ring sequence of living trees (as is habitual in dendrogeomorphology), but rather the dendrochronological dating of manufactured woods (timber elements). In addition to establishing *terminus post quem* dates, i.e., the year in or after which structures were built, dendroarchaeology can assist in the study of remodeling and other alterations to buildings, including the use of timber salvaged from older structures or the replacement thereof [17].

Additionally, these integrated dendrochronological studies permit us to research more than one different type of natural disasters in a wooden building, because the timber elements might have been replaced following several different catastrophes such as floods, thunderbolt fires, earthquakes, etc. In a natural environment, it is not easy to find a forest with trees presenting different external evidence and disturbances in tree-ring sequences caused by different natural disasters and which can be studied with the use of classical dendrogeomorphological methodologies. Furthermore, in the event of various natural disasters recorded in the same forest, it would be difficult to distinguish and separate the different types of events by means of conventional techniques [12].

Historical buildings several centuries old present a complex history of construction involving different timber elements that can be affected by natural disasters over a wider time span. This is the case of the Gothic Medieval cathedrals in European countries, usually tall and thin and prone to be struck by lightning or affected by distant earthquakes (high-wavelength and low-frequency oscillations). This is also true for water-powered industries located in river valley bottoms, such as mills and hydroelectric plants, which are often affected by river floods and other mass movements from the slopes (rockfalls, landslides, avalanches, etc.).

2. Research aim

The present research aims to study three different types of natural disasters (floods, a thunderbolt fire and an earthquake) recorded in the wood elements of two different historical buildings in Segovia, Central Spain (the Old Mint and the Cathedral). In both cases, recent restoration works have provided a unique opportunity to sample their wood elements. The archaeological studies, revealing the presence of deteriorated wood elements (decay and putrescence) that needed to be replaced, enabled sampling to be conducted in coordination with the building works.

Our specific aims are:

- to compile information from several data sources, such as documentary archives and archaeoseismology, about the effects of different natural disasters in the historical construction of these buildings;
- to assign dates, as precise as possible, using dendrochronological and radiocarbon techniques, to the wooden deck of the Old Mint and the Cathedral roof;
- to establish relationships between the timber dates and floods on the wooden deck and the effects of the 1614 fire and the 1755 earthquake on the Cathedral roof and complete the existing information and;
- to promote the use of multidisciplinary techniques in order to contribute with novel findings to the knowledge of historical heritage.

3. The wooden deck of the Old Mint and the wooden roof structure of the Cathedral of Segovia

The materials were collected from two important monuments of the town of Segovia (Central Spain, 60 km North of Madrid; Fig. 1), both declared as World Heritage sites by UNESCO in the year 1986: the Old Mint and the Cathedral. Both buildings rank among the four main monuments of the town, along with the Roman Aqueduct and the Medieval Castle, known as the Alcázar.

The Old Mint, situated in the Eresma river floodplain, was remodeled and put into operation during the reign of King Felipe II by the architect Juan de Herrera (1583–1585). Different minting processes were used here for almost three hundred years to mint coins, until its closure in 1869, when it became a flour mill [18–20]. Some of the minting processes, such as lamination, were powered by water from the nearby Eresma river, by means of a weir, canals and water wheels. During the archaeological research work for its restoration, a wooden deck over the Herrera canal was discovered. It was made of transverse beams and planking nailed in the direction of the canal, and support blocks for the canal structure [14] (Fig. 2a).

Construction of the gothic Cathedral, located at the top of a hill, began during the reign of King Carlos I (1525), following destruction of the old romanesque Cathedral during the Comunidades Civil War (1520–1521). Although designed in the Gothic style, during the three Centuries it took to be finished, Renaissance and baroque elements were gradually incorporated. The roof of the main nave of the Cathedral was completed at the beginning of the 17th Century and it comprised a structure of wooden trusses [21]. On September 18, 1614, a thunderbolt struck the spire crowning the cathedral bell tower, causing a fire that spread to the library and the naves. The tower (at the time the highest one in Spain), as well as most of the roof structure, succumbed to the fire and had to be replaced [21]. Moreover, the Cathedral was subsequently affected by the Lisbon Earthquake, on November 1, 1755. This was the most destructive earthquake in the history of Western Europe, affecting the entire Iberian Peninsula. The city of Lisbon was devastated and many historical buildings in Spain were damaged. The effects of this earthquake were recorded in the survey conducted by King Fernando VI several months later and in many other documents of the time [22]. The damage recorded in the Cathedral of Segovia involved cracks and fractures in the walls and general damage to the chapels (documentary sources: Proceedings of the Chapter of the Cathedral describing the effects of the 1755 earthquake on the building [15]).

The current roof trusses of the Cathedral comprise a unique timber frame (not the typical Spanish armature with rafters and ridge plate), because it is made up of two common rafters, one tiebeam, one collar and two queen struts; additionally, there are rafter braces and raised aisle trusses [23] (Fig. 2b). The whole roof structure is covered by wooden planking and over this, a roof made of tiles. The trusses were tilted and diagonal soulaces between adjacent trusses were added to counteract the inclination and prevent the collapse of the armature [15,24]. In 2014, rehabilitation and renovation work was carried out on the roof of the Cathedral of Segovia (Fig. 1), of which various pieces were replaced due to being in a poor state of conservation; moreover, the soulaces were removed.

These wood samples therefore constitute valuable records of the history of both buildings and of the town affairs.