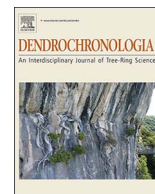




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## ORIGINAL ARTICLE

# Natural hazards and building history: Roof structures of Segovia cathedral (Spain) reveal its history through tree-ring research



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## ARTICLE INFO

## Keywords:

Dendrochronology  
Cathedral roof timbers  
Building history  
Historical research  
Natural hazards  
*Pinus nigra/sylvestris*

## ABSTRACT

Combined dendrochronological and archival research revealed the history of construction and subsequent repairs to the roof structures of Segovia Cathedral, the last gothic cathedral built in Spain. Although this iconic building has been extensively documented by different scholars, the completion date of the 16th century original sacristy was uncertain. Furthermore, disaster struck the building on two occasions, in the 17th and 18th centuries. First, on September 1614, lightning hit the bell tower and fire spread through the roof of the nave. Then, on 1 November 1755, the Lisbon earthquake shook the cathedral building. However, the extent of the damage caused by these events was unknown.

Our combined research revealed that the trees used to make the tie-beams of the sacristy were cut in the late summer/winter months of 1676/77, one century later than the completion date, suggesting that this part of the original sacristy was renewed when a new one was built together with the offices in an annexed building. Furthermore, absolute dates obtained for the nave indicate that the trees used to build the current roof structure were cut in the autumn/winter of 1614/15, which implies that the 16th century original roof must have burned down entirely due to the lightning fire. A historical document registering the purchase of the wood to repair this structure in 1614 confirms this information. Finally, the damage caused by the Lisbon earthquake must have compromised the structural integrity of the roof, as the support timbers used to reinforce it belong to small trees cut in the spring or summer of that same year 1755. Archival research revealed that the roofs were inspected a few weeks after the earthquake, and that repairs were carried out in 1756. This suggests that the wood to prop up the structure was most likely purchased shortly after the inspection (probably in a nearby saw mill where cheap wood from trees cut in the summer of 1755 was available), and before the repairs took place.

## 1. Introduction

The precise historical dating of the original construction and subsequent building phases of major ecclesiastical buildings such as the medieval and later cathedrals of Europe has promoted the development of well-replicated ring-width chronologies, and demonstrated the utility of dendrochronology as a complement to historical documentary research on such architectural heritage. Recent publication demonstrates the utility of this approach, and the detailed timelines for reconstruction in response to intentional destruction by humans, which can be produced through extensive sampling strategies (Haneca and van Daalen, 2017). Equally, techniques have been developed within the discipline of dendrochronology to identify and analyse a range of

natural hazards and disasters including earthquakes, landslips, avalanches and fires (Bekker, 2004; Stoffel, 2008; Trouet et al., 2010; Vasileva and Panayotov, 2016). Such disasters strike not only in the natural environment, but can also affect entire populations, often bringing along the partial or total destruction of historical built heritage. In this case study, an iconic cathedral is researched using a combination of dendrochronology and archival research to shed light on its construction history, and the human response to natural disasters that struck the building on two occasions: lightning strike and subsequent fire, and earthquake.

Segovia cathedral was the last gothic cathedral built in Spain, and is an exceptional monument representative of the Basque-Castilian gothic style (Ruiz Hernando, 1994). After the destruction of the old

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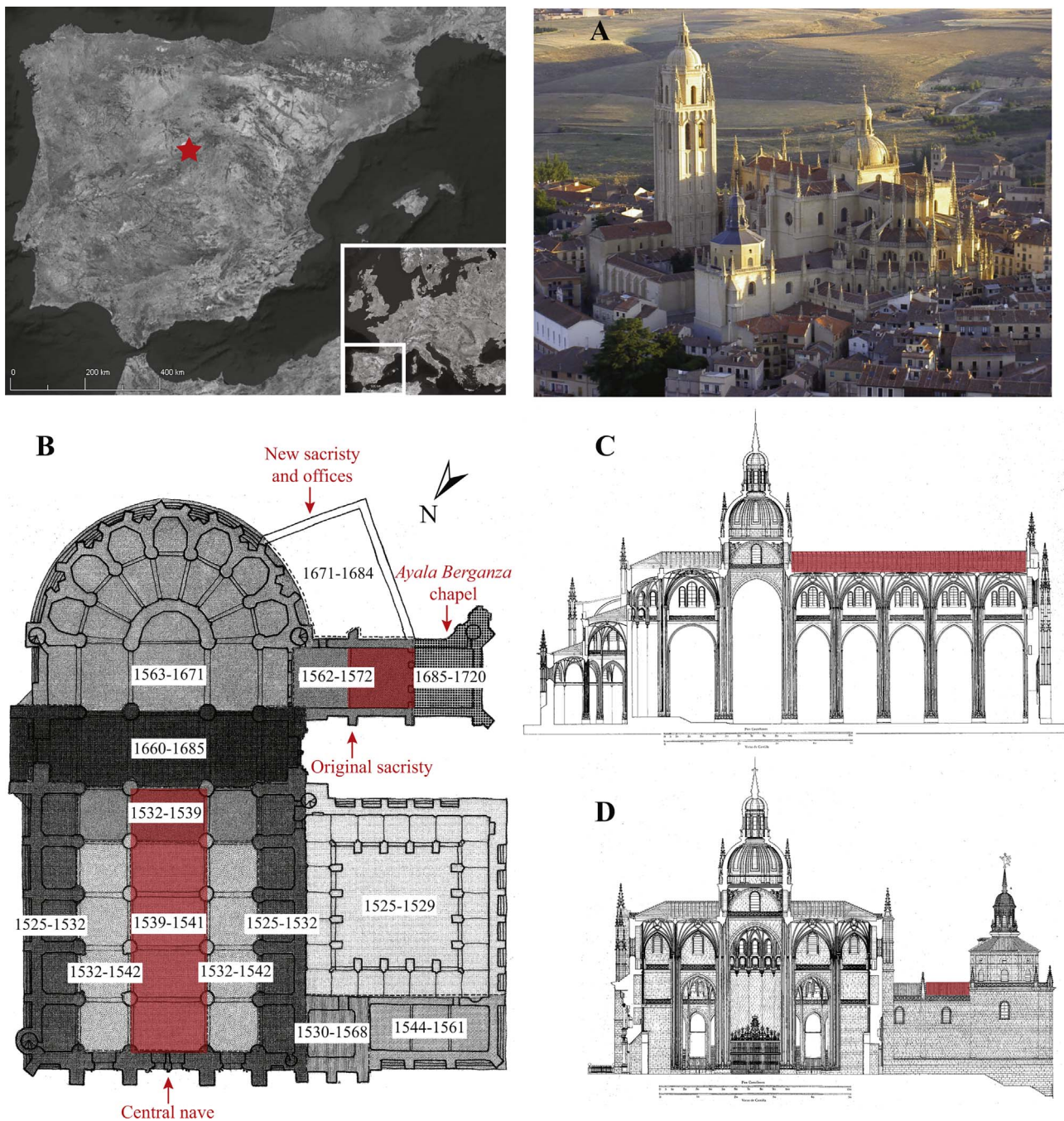
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<http://dx.doi.org/10.1016/j.dendro.2017.09.002>

Received 4 July 2017; Received in revised form 2 September 2017; Accepted 22 September 2017

Available online 28 September 2017

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**Fig. 1.** Location map and different views from Segovia cathedral: A) aerial view courtesy of the Cabildo catedralicio; B) floor plan by A.M. Belouqui indicating construction periods and relevant parts of the building mentioned in the text (adapted from Cortón de las Heras, 1997); C, D) Longitudinal and transversal sections respectively representing the current cathedral building (courtesy of architect J.M. Merino de Cáceres). The red-shaded areas indicate the researched roof structures (nave and western part of the original sacristy).

Romanesque building during the Revolt of the *Comuneros* in 1520, the construction of the new cathedral began in 1525 at its current location, the highest point in the centre of the old town (Fig. 1A). The body of the naves was completed towards 1542, and the rest of the first phase of construction, including the bell tower, in 1557 (Cortón de las Heras, 1997). Other two construction phases followed, the second one from 1558 to 1607, which among other works involved the first sacristy between 1562 and 1572 (Ruiz Hernando, 2003); and the third and final phase from 1607 to 1685, which encompassed the construction of a new sacristy and the offices on the south-western part of the building (Cortón de las Heras, 1997). An additional modification was carried out between 1685 and 1720, when the *Ayala Berganza* chapel, topped by a dome, was added to the western side of the old sacristy (Fig. 1B). This

last addition conferred the cathedral its present-day structure (Figs. 1C,D).

Apart from the cathedral, the city of Segovia holds numerous monumental buildings, among which the exceptionally well preserved Roman aqueduct (1st century CE), and the *Alcazar* fortress (initially built in the 11th century), which together with the cathedral, contributed to the inclusion of the old town centre and the aqueduct in UNESCO's World Heritage List in 1985 ([http://whc.unesco.org/es/list/311\\*](http://whc.unesco.org/es/list/311*), last accessed on 10 May 2017).

The history of this cathedral, however, is not exempt from calamities and uncertainties regarding some construction phases. Historical documents and drawings related to the construction of the original sacristy raise the question of its completion in the 16th century (Ruiz

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