Dendrochronologia 85 (2024) 126212

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

Dendrochronological examination of the Assumption of the Virgin Mary orthodox church in the village of Pades, Greece

A. Elzanowska [a], E. Tsakanika [b], A. Christopoulou [c,d], Y. Özarslan [e], T. Ważny [f,*]

[a] Independent researcher, Poland
[b] School of Architecture, National Technical University of Athens, Athens 10682, Greece
[c] Section of Ecology and Systematics, Department of Biology, National and Kapodistrian University of Athens, Panepistimiopolis, Athens 15784, Greece
[d] Biodiversity Conservation Lab, Department of Environment, University of the Aegean, Mytilene 81100, Greece
[e] Department of Archaeology and History of Art, Koç University, Istanbul 34450, Türkiye
[f] Centre for Research and Conservation of Cultural Heritage, Faculty of Fine Arts, Nicolaus Copernicus University, Toruń 87-100, Poland

A R T I C L E I N F O

Keywords:
Dendrochronology
Historical wood
Greek cultural heritage
Pinus heldreichii
Pinus nigra
Quercus sp

A B S T R A C T

The current study is a dendrochronological analysis of the wood from the church of the Assumption of the Virgin Mary, Pades, Greece which was built towards the end of the 18th century according to historical sources. The tree-ring analysis shows that the date, 1784, given on the inscription at the main entrance of the church probably documents the year when the construction works began, and that there were several construction stages of the structural and decorative elements of the church until the early 19th century. Moreover, the oldest (reused) timber elements that were identified through the dendrochronological study date back to the first half of the 15th century and may indicate the first traces of the construction activity in and around Pades. The dendrochronological study enabled the development of three local reference chronologies for the Epirus region. The timespan for the developed chronologies for the church in Pades is: 1262–1825 for *Pinus heldreichii* (Bosnian pine), 1295–1854 for *Pinus nigra* (Black pine), and 1571–1767 for *Quercus* sp. (Deciduous oak).

1. Introduction

Dendrochronology is the science that analyzes tree-ring patterns for dating past events (Fritts, 1976; Cook and Kairiukstis, 1990). It has application in different disciplines, including archaeology, architecture, and heritage studies. This gave rise to the emergence of dendroarchaeology, a science that studies historical and archaeological wood from a diverse set of contexts. Through the examination of historical timber elements, wooden structures can provide information about wood species used, forests that provided them, and the construction date of historical buildings. Moreover, when coupled with structural and architectural analyses, it can also contribute to a better understanding of different construction phases and past interventions.

In Greece dendroarchaeology was first applied during the 1980 s, when P. I. Kuniholm and C. L. Striker began to collect and analyze tree-ring series from historic buildings, forests, and archaeological sites in Greece and the surrounding Aegean region (Kuniholm and Striker, 1983, 1987). We returned to this topic to create a solid basis for dating wood in mainland Greece, in the Peloponnese (Makris et al., 2021, Christopoulou et al., 2023), Crete (Christopoulou et al., 2019, Ważny et al., 2020b), and the islands of the Aegean Sea (e.g. Ważny et al., 2020a). Dendroarchaeology added a great value and potential via multidisciplinary studies to our understanding of the historical and traditional architecture in the Epirus region, but so far, the only dendroarchaeological study from this mountainous area investigated the Monastery of St. Nicolaus in Metsovo (Christopoulou et al., 2022).

Collecting new wood samples from historical buildings is essential to develop long and well-replicated historical reference chronologies, especially from regions that have not been sufficiently explored. In order to demonstrate the value of dendroarchaeological studies in the Epirus region, an examination of the 18th-century orthodox church of the Assumption of the Virgin Mary was carried out as a case study. The church is located in NW Greece, a few kilometers from the Greek-Albanian border, in the village of Pades near Konitsa (prefecture of Epirus), hidden on the slopes of Mt. Smolikas at an altitude of 1140 m (Fig. 1). It falls within the borders of the Northern Pindus National Park, the largest terrestrial national park in Greece. Within the National Park there are several vegetation types, with Black pine (*Pinus nigra*) being

* Corresponding author.
E-mail address: twazny@umk.pl (T. Ważny).

https://doi.org/10.1016/j.dendro.2024.126212
Received 24 December 2023; Received in revised form 25 March 2024; Accepted 7 May 2024
Available online 10 May 2024
1125-7865/

Fig. 1. Location of the research site in Greece.

the dominant tree species, found mostly within the altitudinal zone of 1000–1600 m. Bosnian pine (*Pinus heldreichii*), the second most common pine species within the National Park, dominates along the zone of boreal conifers (1600–2000 m).

The aim of this study is to provide information about the timber choice and the construction date and to identify the different construction phases of the church of the Assumption of the Virgin Mary. The study also demonstrates the potentials and benefits of dendrochronology in studying historical buildings - by developing new reference chronologies for dating and dendroprovenancing purposes.(Fig. 2)

2. Materials and methods

According to the inscription at its entrance (Fig. 3), the church was

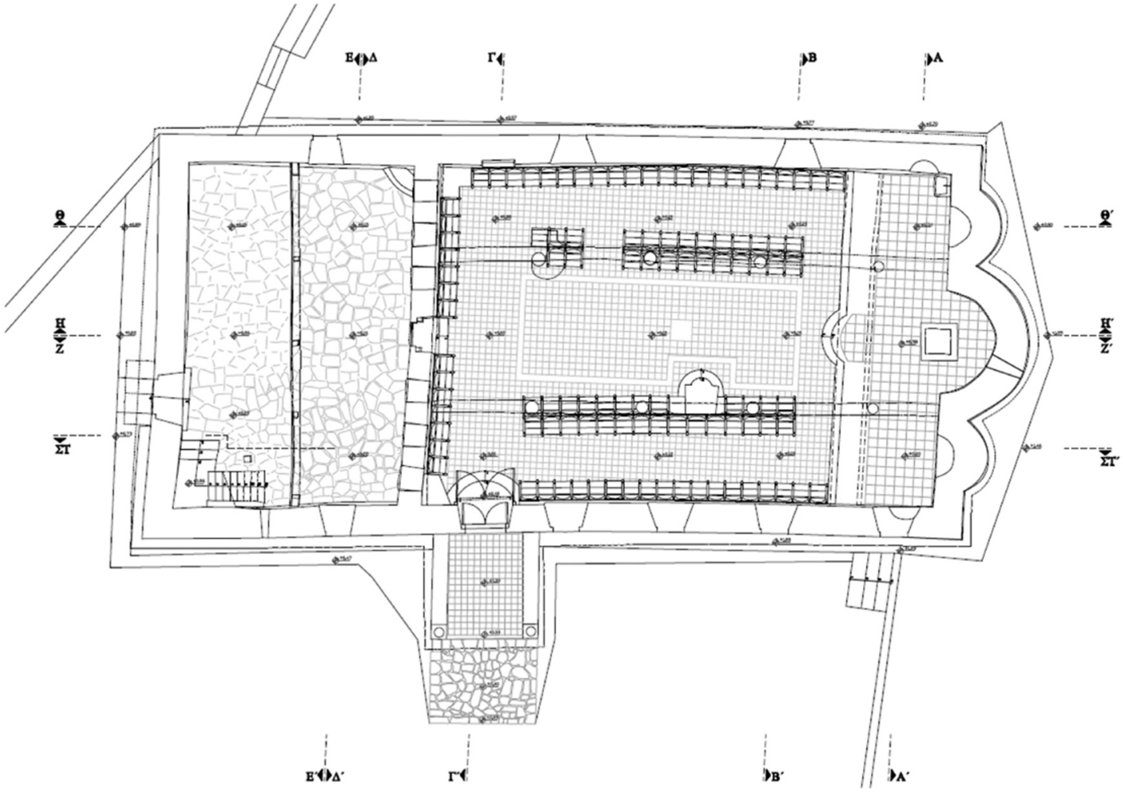

Fig. 2. Plan of the ground level (Architectural study: Margarita Alexiou).

Fig. 3. The porch in front of the main entrance with an inscription above the door and an internal view of the church.

built in 1784. The church is a timber-roofed basilica with three aisles, typical of the NW region of Greece, two entrances, and with few windows, mainly on the northern and southern walls. The main entrance is on the southern wall and protected by a stone porch built and painted at the beginning of the 20th century (Figs. 2, 3). The second one is on the western wall (Figs. 2, 3).

The walls are made of rubble stone masonry reinforced by a

Fig. 4. The timber columns in the nave and on the ground and upper floors of the narthex.

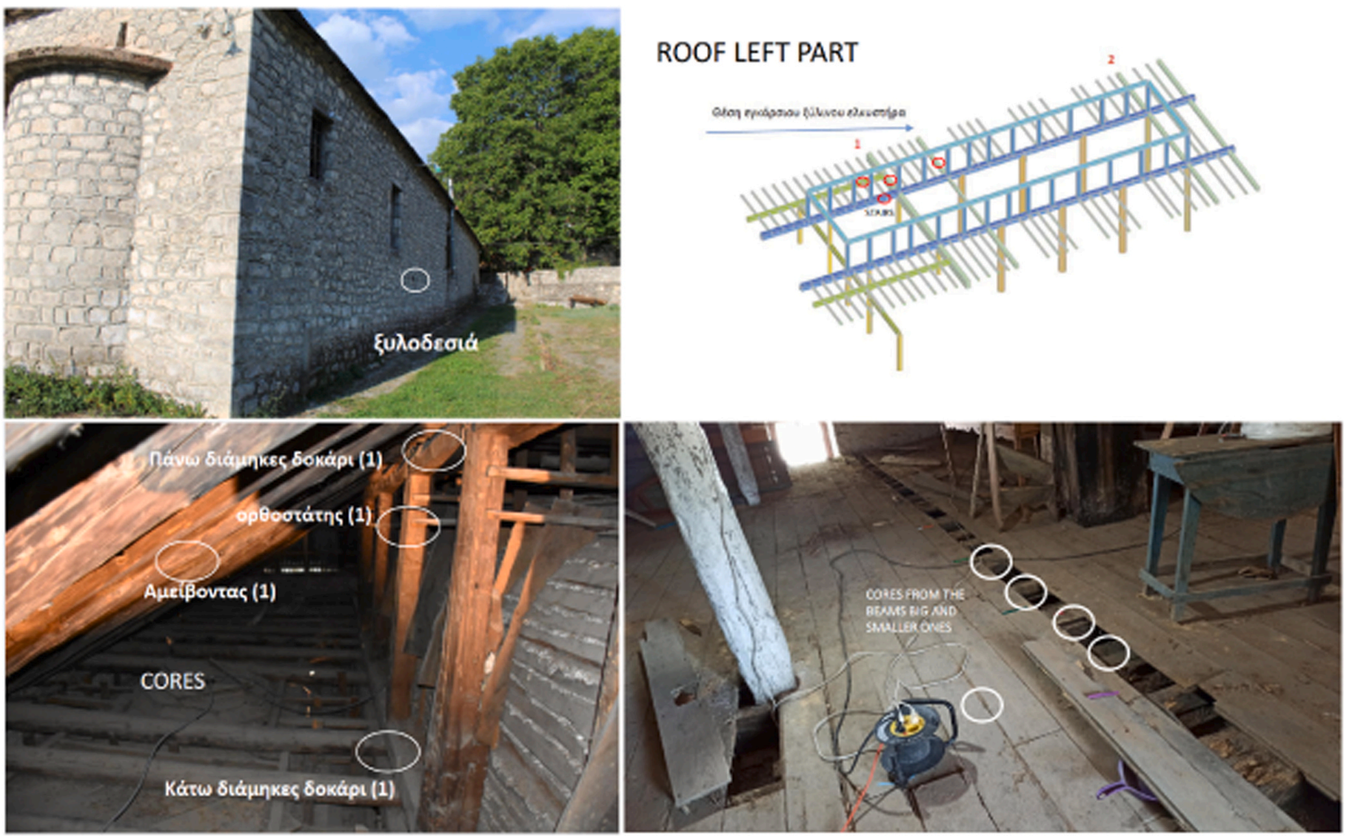

Fig. 5. Locations recommended for sampling by the team responsible for the restoration study (including the roof floor and timber reinforcements of the masonry walls).

horizontal timber system, composed of longitudinal and transversal timbers.[1] The system is invisible from the outside of the church since it is hidden behind a row of stones, but visible from the inside, mainly at the upper part of the narthex where the plaster of the walls is missing.

The internal colonnades of the basilica, between the nave and the aisles, are made of wood (Fig. 3 and Fig. 4). These timber columns support the longitudinal horizontal beams through a short piece of timber. The same system is used for the columns in the narthex, supporting the floor, the roof, and the timber parapet between the narthex and the main church (Fig. 4).

During our on-site inspections, various timbers were selected for sampling, based on the suggestions and comments made by the team responsible for the restoration study. This was essential for the dendrochronological results to be interpreted in the light of the historical, architectural, and structural studies of the monument (Fig. 5). The type, position, and importance of each timber as a historical element determined which samples should have been collected. Another criterion for sample selection was the highest possible number of preserved tree-rings. As a result, 66 samples were collected in total.

Most of the timbers were sampled by taking cores with the use of a modified electric drill. Stored timbers that had been removed from the construction during restoration works were cut in the form of slices with the use of a Japanese handsaw. Where the end grain of the timbers was exposed (e.g., within the reinforcement system of masonry), non-destructive methods (polishing the end-grains with a sandpaper and taking high-resolution photographs) were applied. These photographed surfaces with visible tree-ring boundaries were measured with the use of CooRecorder software (Cybis Elektronik & Data AB).

The sample preparation, measurements, and further analyses

[1] The horizontal reinforcement system of masonry, a timber grid of longitudinal and transversal timbers, is called "*xylodesia*" in Modern Greek and "*imantosis*" in Ancient Greek. Its main structural role is to tie buildings and reinforce them against earthquakes (Tsakanika, 2017).

Fig. 6. a) Black pine (*Pinus nigra*) sample with visible brighter and wider sapwood area; b) Bosnian pine (*Pinus heldreichii*) sample with narrow and not-easily-distinguishable sapwood area.

followed traditional dendrochronological methods (Baillie, 1982; Schweingruber, 1988). Before measuring, sample surfaces were prepared with sandpapers and/or blades until tree-ring boundaries and anatomical features were clearly visible under magnification.

Since macroscopic identification of coniferous tree species may be impossible in some cases, microscopic identification of all wood samples was necessary. Identification was based on the observation of cross, tangential, and radial sections under a biological microscope by comparing wood structures against existing reference materials. It was particularly important to distinguish the two pine species, *P. heldreichii* and *P. nigra*, found in the structures because of their different ranges of occurrence. The main difference between the two pine species is visible under the microscope in the radial section. Black pine has characteristic features, such as cross-fields with one to two window-like large pits and ray tracheids with clearly visible dentate walls, while Bosnian pine has pinoid pits in its cross-fields and ray tracheids with smooth or slightly dentate walls. The number of rays per 1 mm^2 and the height of the rays in the tangential section are also different between the two species. The height of rays in Bosnian pine varies from 1 to 30 cells (Akkemik and Yaman, 2012) while in Black pine it can reach a maximum of 15 cells.

Samples were examined with the use of an Olympus microscope under 50–400x magnification in transmitted light. Results of observation were compared with wood-anatomical atlases and reference materials in the form of micro-slices (Wheeler, 2011). Tree-ring widths were measured with an accuracy set to 0.01 mm using Time Series Analysis and Presentation (TSAP) software package (Rinn, 2011) and LINTAB measuring table (Rinntech®).

As a second step, the measurements of each sample were compared with those from the rest of the samples. Cross-dating and chronology building was performed separately for each of the identified species.

The newly-developed chronologies were cross-dated and synchronized against available reference chronologies from the broader study area. This was done separately for *Pinus nigra*, *Pinus heldreichii*, and *Quercus* sp. Both visual and statistical cross-dating was carried out. For statistical cross-dating the following parameters were used: *Gleichläufigkeit* (Glk) – which represents the percentage of year-to-year changes in ring widths which are the same (both increasing or both decreasing) between the ring-width sequence in a section and the reference chronology (Eckstein and Bauch, 1969), t–value Hollstein (TVH) (Hollstein, 1980) which are sensitive to extreme values, such as marker years. TVH values above 4.0 were considered as significant. We also analyzed the Cross-Dating Index (CDI), which combines all correlation measures (Rinn, 2011) and is significant for CDI>25. The common interval expressed by the number of overlapping years (OVL) was also considered. TSAPWin (Rinn, 2011) and DENDRO for Windows 10 (Tyers, 2004-2019) were used for cross-dating and visualization of our results.

3. Results and discussion

3.1. Species identification and tree-ring pattern

Our analysis shows that two pine species, Black pine (*Pinus nigra*) and Bosnian pine (*Pinus heldreichii*), were used for the timber elements of the church, including the roof, ceiling, narthex floor, and narthex columns. They were mixed in a structural timber construction. For the longitudinal timbers of the inner leaf of the external masonry walls, the longitudinal timbers embedded in the outer leaf of the masonry walls, and the transversal ones, deciduous oak (*Quercus* sp.) was used with an addition of Black pine. The potential oak species in this part of Europe are Valonia oak (*Quercus ithaburensis* subsp. *macrolepis*), Turkey oak (*Quercus cerris*), downy oak (*Quercus pubescens*), and sessile oak (*Quercus petraea*) (EUFORGEN, 2021).

Besides microscopic identification, the macroscopic analysis of the samples also clearly shows the difference between the two pine species. In Black pine the sapwood area is much wider and easily visible with the naked eye. Sapwood in Black pine may also have a slightly gray blue color (Fig. 6a) resulting from fungal activity causing wood discoloration. In Bosnian pine the sapwood area is much narrower (Fig. 6b).

Oaks are characterized by excellent durability (biological resistance against wood-destroying organisms, such as insects and fungi), as well as high hardness and strength. Deciduous oaks are commonly used for wooden constructions in the Mediterranean region (Macchioni et al., 2012; Bernabei et al., 2020; Tegel et al., 2022), including Greece (Kuniholm and Striker, 1983; 1987; Ważny et al., 2020; Christopoulou et al., 2020; Makris et al., 2021). Deciduous oaks are also among the most useful and commonly used species in timber dating (e.g. Haneca et al., 2009; Edvardsson et al., 2021; Tegel et al., 2022). It should be noted that old mansions in the Epirus region intentionally used a different, more durable species, such as oak rather than pine, for timbers that are more exposed to decay problems, such as the outer longitudinal and transversal timbers used in timber reinforcement systems embedded in external masonry walls. Pine was preferred for the longitudinal timbers placed in the inner phases of the masonry walls of the same timber reinforcement systems, as well as for columns, floors, roofs, and ceiling constructions inside the buildings.

In this study, the results of wood identification for the timber floor of the narthex revealed that Bosnian pine was preferred for the beams and the pillars of the ground floor. On the upper floor and in the structural part of the ceiling only Black pine was identified while the roof construction consists of timbers representing both pine species. Amongst the stored timbers, which had been removed probably during previous restoration works, or moved for storage from another site, only *P. heldreichii* was identified.

Well-preserved bark edge was mostly found in the roof construction. Nearly half of the samples from the ground floor of the narthex and its upper floor also had visible bark edge. In such cases it was possible to

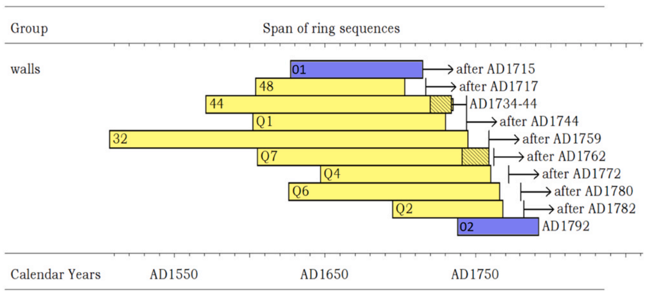

Fig. 7. The chronological span of the dated timbers from the external masonry walls of the church. Oak samples are in yellow, pine samples are in purple. The graph was prepared in DENDRO for Windows (Tyers, 2004).

date elements with accuracy to one year. In the walls and ceiling only some of the elements had preserved bark edge, and if preserved, severe destruction caused by insects made it impossible to obtain a complete sample.

3.2. Dating

Fifty-one (51, 77 %) of the 66 collected samples were absolutely dated. Sixteen (16) among them were dated with annual precision. A thorough analytical study of the dated samples in conjunction with the historical, architectural, and structural study of the monument will be presented in another paper.

3.2.1. External masonry walls (horizontal timber reinforcement system)

Ten (10) samples were collected from the external masonry walls of the church. All of them were qualified for further dendrochronological analysis. Five (5) of them were *P. nigra* belonging mainly to the longitudinal timbers of the inner leaf of the masonry walls, while five (5) of them were *Quercus* sp. belonging mainly to the ends of the transversal timbers of the horizontal timber reinforcement (Fig. 5). Bark edge was visible only in two (2) *P. nigra* samples; therefore, we were able to date them with an accuracy to one year or season. For oak samples we were able to apply sapwood statistics. The number of sapwood rings varies among oak species and different regions (e.g., Miles, 1997, Haneca et al., 2009). According to Kuniholm and Striker (1987), for this part of Greece an average of 26±9 sapwood rings should be added. The general chronological span of the timbers from the walls covers a period from the 1740 s to 1792. According to this chronological span, we can conclude that the external walls were built of timbers cut at the end of the 18th century (Fig. 7), and these are the youngest amongst all the timbers analyzed by us. The youngest dating is eight (8) years younger than the date (1784) given on the inscription at the main entrance of the church. This may suggest that the date 1784 may have documented the year when the construction works began, and the external wall was still

Fig. 8. Dated roof posts and curved elements of the load-bearing timbers of the vaulted central ceiling.

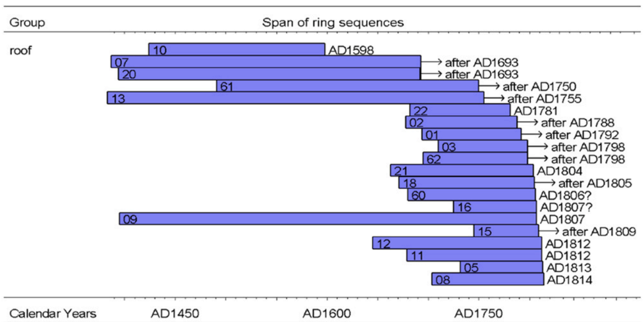

Fig. 9. The chronological span of the dated timbers from the barrel vault structure and the roof construction of the church. Question mark indicates uncertain bark edge. The graph was prepared in DENDRO for Windows (Tyers, 2004).

under construction in 1792. The samples from the horizontal timber reinforcement of the masonry are valuable since they allow us to accurately date the original structure and the beginning of the construction work given the fact that those timbers had been incorporated in the walls at the time of construction. The samples from the floor or the roof may belong to later interventions or indicate a building phase of the original structure, providing clues for the time needed for the construction of the building.

3.2.2. *Roof and vaulted central ceiling*

Twenty-six (26) pine samples were taken from the roof (Fig. 5) and the vaulted ceiling of the central nave of the church. Twenty (20) of these samples (77 %) were dated. Ten (10) samples had well-preserved bark edge; therefore, it was possible to date them with an accuracy to one year or season. The timber samples from this part of the building equally represented the two pine species. It is obvious that the three posts holding the roof are much older – one was cut in 1598 while the two others were cut after 1693, indicating that they may be of secondary use (Figs. 8, 9). It is also apparent from the characteristic woodworking tool marks on the roof posts that all of them were trimmed with a vertical saw and their surfaces were roughly leveled by an axe. All the other posts are much younger, from the beginning of the 19th century. Curved timber elements from the load-bearing system of the vaulted central ceiling (Figs. 8, 9) are a few years younger (years 1812–1814), providing hints for the construction date of the ceiling. These dates may also suggest timber stockpiling - small local community and difficult

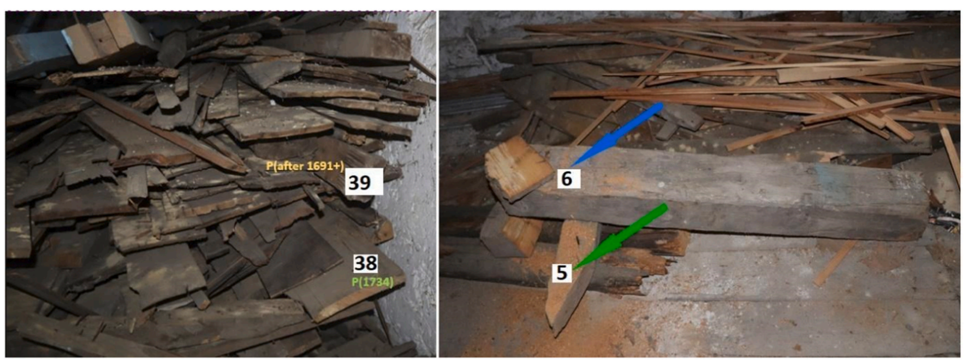

Fig. 10. Timbers found in a pile stored on the floor of the narthex.

Fig. 11. Revealed beams from the floor of the narthex (Samples 33, 36–37, 40).

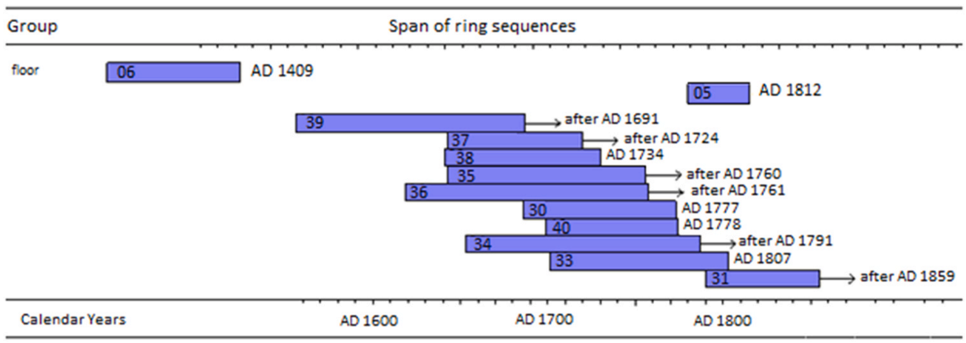

Fig. 12. The chronological span of the dated timbers from the floor of the narthex and the stored timber pile. The graph was prepared in DENDRO for Windows (Tyers, 2004).

Fig. 13. Reused column – Sample 9.

mountainous conditions may have not allowed for construction investments on a large-scale.

3.2.3. *Timbers from a pile stored on the floor*

Six (6) samples were collected from a pile of timbers stored on the upper floor of the narthex (Figs. 10, 11). These timbers showed traces of former use and may have been stored there for reuse and recycling during potential future restoration works. Two of them (Samples 38 and 39) provided older dates (after 1691 and 1734 respectively).

3.2.4. *Floor of the narthex*

Six (6) samples from the beams (joists) and two (2) samples from two planks belonging to the floor of the narthex (Figs. 4, 5 and Fig. 11 and Fig. 12) were collected. All these samples were identified as Black pine. Three (3) samples had preserved bark edge. The two planks of the flooring (Samples 30 and 31) were also dated. Plank 30 had a bark edge, and its date shows that it belongs to the original flooring, while Sample 31 was probably used during a later intervention (after 1859). The floor planks are usually one of the most frequently restored parts of the building.

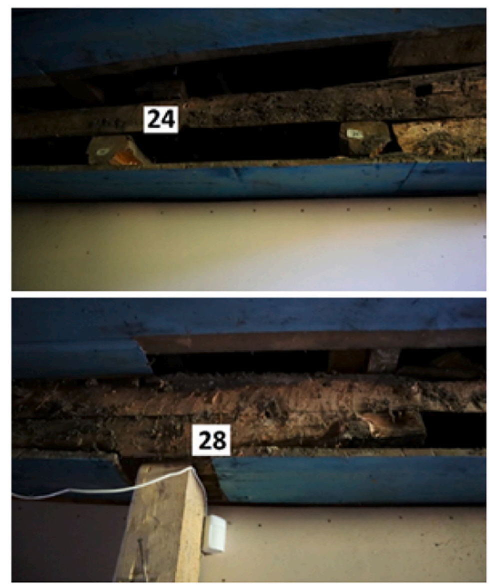

Fig. 14. The main intermediate beam supporting the floor beams – Sample 24 (dating after 1674) and the bedding timber between the main beam and the column – Sample 28 (dating after 1728).

Among the oldest timbers (Sample 9) with visible traces of surface leveling with an axe, another example is an element from the ground level of the narthex that was reused as a column for the main intermediate longitudinal beam of the floor on which the beams (joists) of the floor rest (Fig. 13). Cutting year of the intermediate beams supporting the floor beams can be tentatively placed in the second half of the 18th century at the earliest due to their heavily damaged outer parts destroyed by insects and the numerous missing outer rings (Fig. 14).

Conifer beams in the wall next to the entrance door may have been used for the insertion of the southern entrance. Both are dated to a few years following 1826 (Fig. 15).

We developed three mean chronologies for each species: PadesPiNi for Black pine, PadesPiHe for Bosnian pine, and PadesQu2 for oak (Table 1). The Black pine chronology has the highest number of the included tree-ring series. Both Black pine and Bosnian pine chronologies cover a long period – approximately 560 years in each. Although the oak chronology has the lowest number of the included tree-ring series, it covers 196 years. The newly-developed mean chronologies were subsequently cross-dated against reference chronologies from the surrounding and/or broader areas. Results are presented in Tables 2–4 and Figs. 16–18.

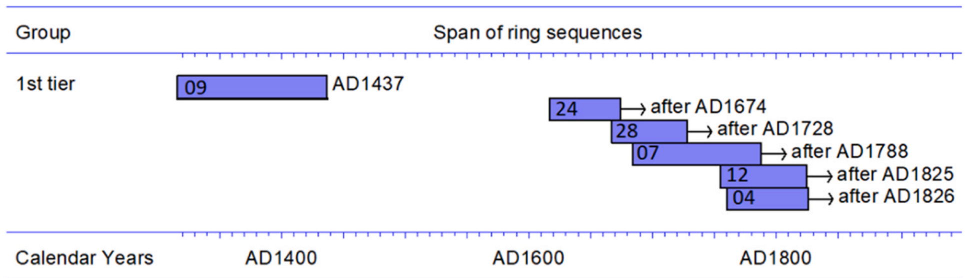

Fig. 15. The chronological span of the dated timbers from the ground floor of the church. The graph was prepared in DENDRO for Windows (Tyers, 2004).

Table 1
Descriptive statistics of the developed PadesPiNi, PadesPiHe and PadesQ2 mean chronologies.

Developed mean chronology	Species	Number of dated series included	From – To
PadesPiNi	*Pinus nigra*	36	1295–1854
PadesPiHe	*Pinus heldreichii*	14	1262–1825
PadesQu2	*Quercus* sp.	7	1571–1768

Table 2
Cross-dating results of the developed PadesPiNi chronology against *Pinus nigra* reference chronologies from Greece.

Reference chronology	Site name	Reference	TVH	CDI	Glk	OVL
MAL0001m	Greece, Malakasi	Christopoulou, Ważny (unpubl.)	10.6	58	69	178
ANMPINI2	Greece, Metsovo, St. Nicolaus Monastery	Christopolou et al. (2022)	7.3	52	68	178
PALSELPS	Greece, Palaioseli	Christopoulou et al. (in prep.)	7.0	47	63	560
ANMPINI1	Greece, Metsovo, St. Nicolaus Monastery	Christopolou et al. (2022)	6.1	41	69	245

TVH = t–value Hollstein; CDI = Cross-Dating Index; Glk = Gleichläufigkeit; OVL = number of overlapping years.

Table 3
Cross-dating results of the developed PadesPiHe chronology against *Pinus heldreichii* reference chronologies from Greece and the neighboring countries.

Reference chronology	Site name	Reference	TVH	CDI	Glk	OVL
GrGreven	Greece, Grevena	Kuniholm (unpubl.)	16.0	111	69	564
Smolikas	Greece, Mt. Smolikas	Klippel et al. (2017)	15.9	106	68	564
PALSELPH	Greece, Palaioseli	Christopoulou et al. (in prep.)	12.5	84	66	555
Albania2 (ALB002)	Albania, Fushë-Lurë	Seim et al. (2012)	11.5	75	65	564
MAVRO01m	Greece, Mavrovouni	Christopoulou et al. (2022)	12.0	69	65	418

TVH = t–value Hollstein; CDI = Cross-Dating Index; Glk = Gleichläufigkeit; OVL = number of overlapping years.

3.3. Timber origin

The timber origin may be interpreted based on our dendrochronological analysis and the results of synchronization with reference chronologies. From the statistical comparison of both PadesPiNi and PadesPiHe chronologies and the reference chronologies we can assume that the timber used for the construction of the church was certainly of local origin. PadesPiNi gives the best correlation with timbers from Malakasi – a forest site located 7 km NW of Metsovo. (Fig. 16). From the comparison of the PadesPiHe chronology against the reference chronologies we can assume that these timbers were transported over a short distance – not more than 80 km from Pades. The overlap for all the

Table 4
Cross-dating results of the developed PadesQu2 chronology against reference *Quercus* sp. chronologies from the neighboring countries.

Site name	Reference	TVH	CDI	Glk	OVL
Oak chronology for the former Yugoslavia in the 16th-19th c.	Kuniholm (unpubl.)	6.6	43	64	196
N. Macedonia, Ohrid, Hg.Sophia	Kuniholm (1996)	5.6	33	65	103
Western Greece	Griggs et al. (2007)	5.0	32	59	196
Northern Greece	Griggs et al. (2007)	5.0	32	57	196

TVH = t–value Hollstein; CDI = Cross-Dating Index; Glk = Gleichläufigkeit; OVL = number of overlapping years.

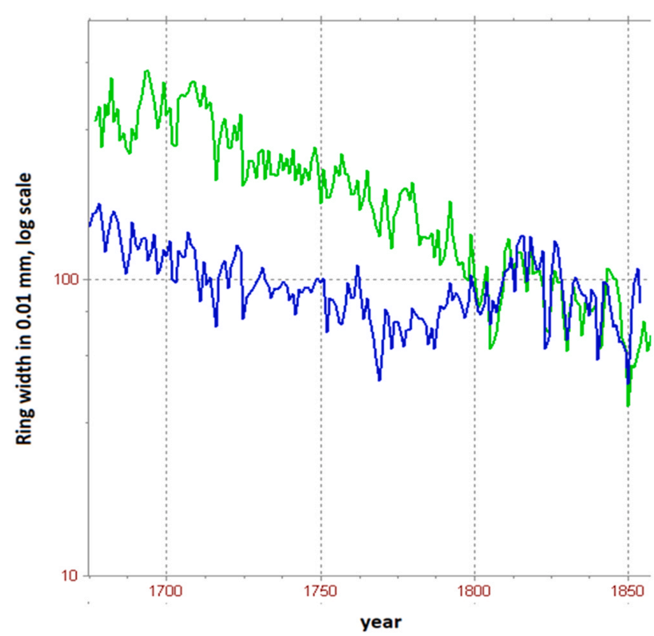

Fig. 16. Visual cross-matching of the developed mean *Pinus nigra* chronology (PadesPiNi in blue) and the reference Malakasi Black pine chronology (MAL0001m in green) providing the best cross-dating results. Only the overlapping period of the reference chronology is presented here.

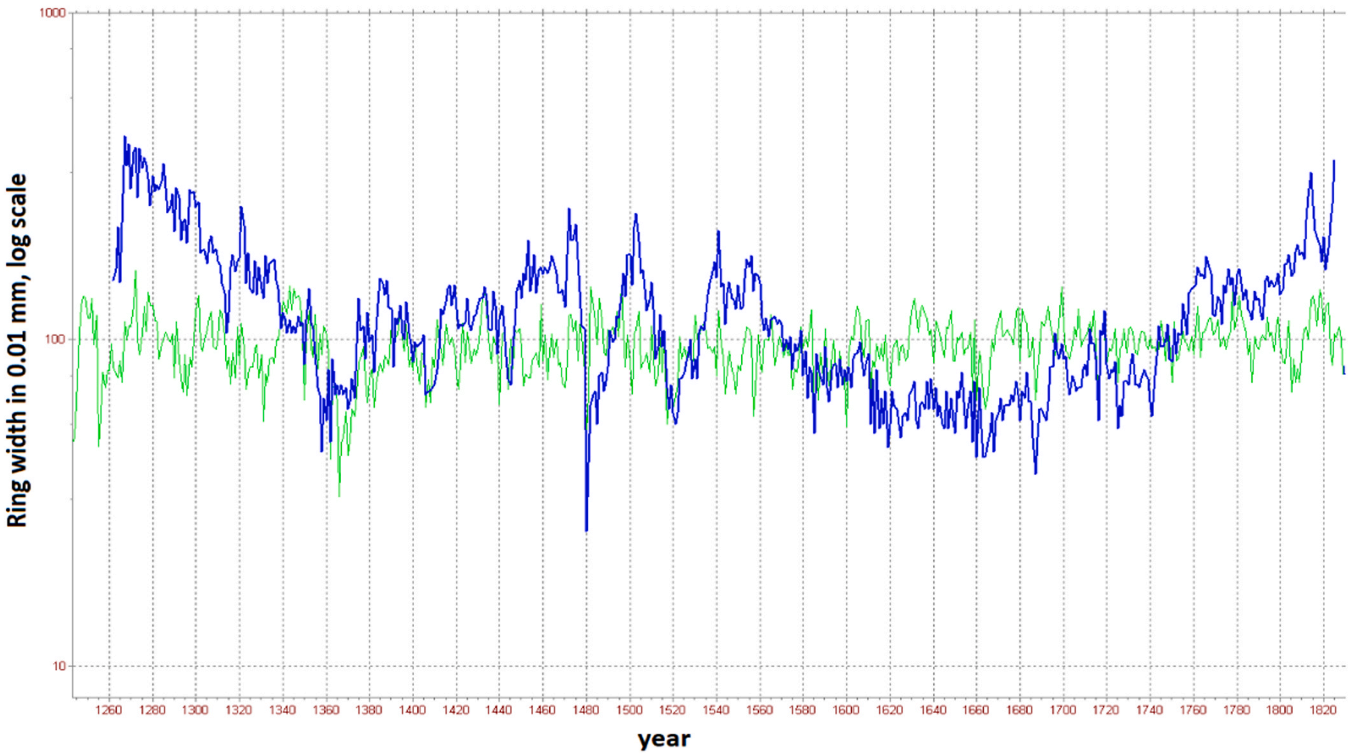

Fig. 17. Visual cross-matching of the developed mean *Pinus heldreichii* chronology (PadesPiHe in blue) and the reference Bosnian pine chronology from the forests around Grevena (GrGreven in green) providing the best cross-dating results. Only the overlapping period of the reference chronology is presented here.

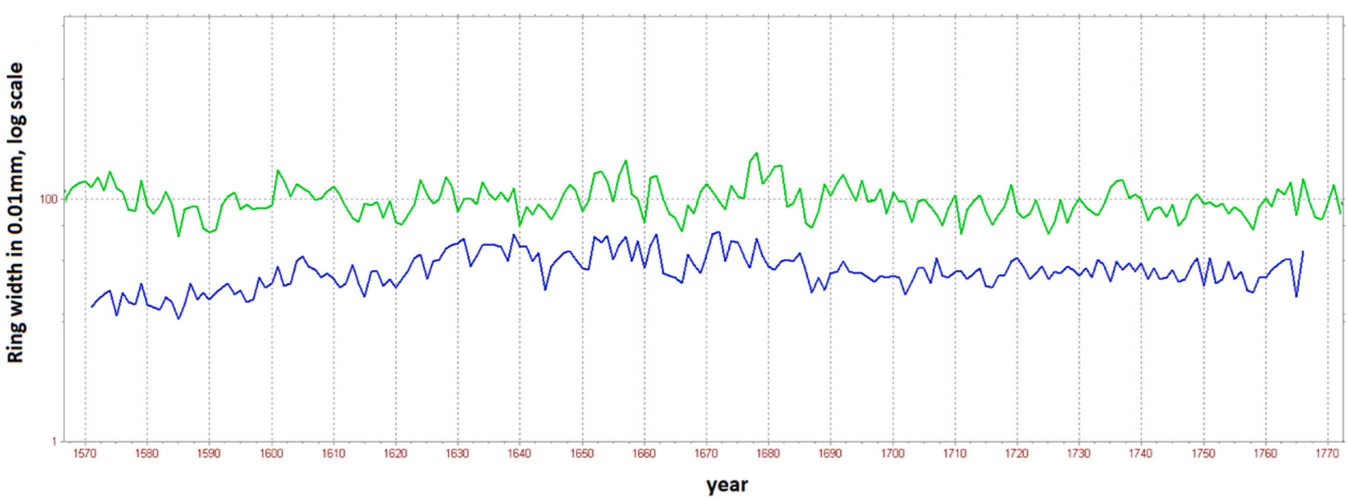

Fig. 18. Visual cross-matching of the developed mean *Quercus* sp. chronology (PadesQu2 in blue) and the reference SW Balkans oak chronology (Yugo1619 in green) providing the best cross-dating results. Only the overlapping period of the reference chronology is presented here.

presented reference chronologies is very high and mostly covers the whole period for the PadesPiHe chronology (Fig. 17). We can also observe high correlations between PadesQu2 and the oak chronologies developed for the former Yugoslavia and Greece. The best parameters are given by the chronology constructed for oak timbers collected from the southern part of the former Yugoslavia. This chronology also overlaps with PadesQu2 for the entire period (196 years). Chronologies from Ohrid (Northern Macedonia), northern Greece, and western Greece also correlate well. The high correlation against northern Greece, a region represented mainly by historical timbers from Thessaloniki, reflects import of Balkan oak to the Aegean. Akkemik et al. (2019) registered high amounts of the Balkan oak found at the Ottoman jetty in the Yenikapı harbor in Istanbul, constructed at the same time. However, there is no sufficient information or data providing the precise location concerning the oak timber origin (Fig. 18).

4. Conclusions

In this study we analyzed constructional and structural wood from the orthodox church of the Assumption of the Virgin Mary in Pades, Greece. Our tree-ring analysis enabled the development of three new chronologies for Bosnian pine, Black pine, and deciduous oak for the Epirus region in Greece. The developed chronology for Bosnian pine covers more than 560 years (with tree-ring series going back to AD 1260) and correlates with reference chronologies from Mt. Smolikas and the nearby forests. This shows that the timber used for the church of the

Assumption of the Virgin Mary in Pades was of local origin.

The percentage of the dated samples from the church in Pades is high (~ 77 %). Sixteen (16) of these samples were dated with annual precision. The first results of our dendrochronological analysis show that the date (1784) given on the inscription at the main entrance of the church may be documenting the year when the construction works began, and that the external wall was still under progress in 1792, eight years after the start of the construction. A possible date for the floor and the roof construction is after 1807. The barrel vault was probably constructed in the years 1812–1814. Traces of later local interventions also exist, such as the new planks inserted into the floor in 1859.

During our examination re-used timbers dating to several centuries prior to the actual age of the church building were also found. This finding confirms the high quality and resistance of Bosnian pine wood (Klippel et al., 2017) and suggests that Bosnian pine timber was recycled in the region.

An analytical study of the dated samples in conjunction with the historical, architectural, and structural study of the monument will be subject to the next phase of our research. In this paper the results of our dendrochronological analysis are briefly presented, showing the importance of dendrochronology, not just for dating, but also for an in-depth documentation of cultural heritage buildings, unfolding new aspects of their history (routes of timber supply, construction stages, interventions, etc.), for which information is usually either scanty or missing.

CRediT authorship contribution statement

A.Elzanowska: Writing – original draft, Investigation. **E.Tsakanika:** Writing – review & editing, Resources. **A.Christopoulou:** Writing – review & editing. **Y. Özarslan:** Writing – review & editing. **T.Ważny:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of Competing Interest

All co-authors of the paper declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The timber examination was carried out within the framework of the Balkan-Aegean Dendrochronology Project "*Tree ring research for the study of SE-European and East Mediterranean Civilizations*" funded by the National Science Center, Poland, project nr 2016/22/A/HS3/00285. The examination of the wood samples was implemented under the required permission from the Ephorate of Antiquities of Ioannina and the Hellenic Ministry of Culture and Sports (ΑΔΑ: 9ΒΦΑ4653Π4-ΨΙ9, ΥΠΠΟΑ 19/0582022, Α.Π.: 407854) and the consent of the Metropolis of Ioannina in the context of the restoration study of the monument, conducted by M. Alexiou, N. Psilla, E. Tsakanika, S. Tsouka, K. Andritsos, and T. Kouimtzoglou and funded by the Prefecture of Epirus.

References

Akkemik, Ü., Yaman, B., 2012. Wood Anatomy of Eastern Mediterranean Species. Verlag Kessel Publishing House, Germany, p. 310.

Baillie, M.G.L., 1982. Tree-Ring Dating and Archaeology. Croom Helm, London and Canberra.

Bernabei, M., Brunetti, M., Macchioni, N., Nocetti, M., Micheloni, M., 2020. Surveying and dating the wooden roof structure of st francis of assisi church in valletta, malta. Int. J. Archit. Herit. 15, 1886–1894. https://doi.org/10.1080/15583058.2020.1734688.

Christopoulou, A., Gmińska-Nowak, B., Özarslan, Y., Krąpiec, M., Ważny, T., 2023. Reconstructing the oaks' growth patterns in Greece with the use of historical timber: case studies from Western Peloponnese. Dendrochronologia 80, 126110. https://doi.org/10.1016/j.dendro.2023.126110.

Christopoulou, A., Gmińska-Nowak, B., Tsakanika, E., Ważny, T., 2022. Discovering the unknown history of the utilization of pinus heldreichii in wooden structures by means of dendroarchaeology: a case study from Metsovo (Northern Greece). Forests 13, 719. https://doi.org/10.3390/f13050719.

Christopoulou, A., Ważny, T, Moody, J., Tzigounaki, A., Giapitsoglou, K., Fraidhaki, A., Fiolitaki, A., 2019. Dendrochronology of a scrapheap, or how the history of Preveli Monastery was reconstructed. Int. J. Archit. Herit. 2–15. https://doi.org/10.1080/15583058.2019.1685023.

Cook, E.R., Kairiukstis, L.A., 1990. Methods of Dendrochronology: Applications in the Environmental Sciences. Springer, New York.

Eckstein, D., Bauch, J., 1969. Beitrag zur rationalisierung eines dendrochronologischen verfahrens und zur analyse seiner aussagesicherheit. Forstwiss. Cent. 88 (4), 230–250.

Edvardsson, J., Almevik, G., Lindblad, L., Linderson, H., Melin, K.-M., 2021. How cultural heritage studies based on dendrochronology can be improved through two-way communication. Forests 12, 1047. https://doi.org/10.3390/f12081047.

EUFORGEN, 2021. Forest Genetic Resources Strategy for Europe., 2021. European Forest Institute. ⟨https://www.euforgen.org/⟩.

Fritts, H.C., 1976. Tree Rings and Climate. Academic Press, London.

Griggs, C.B., DeGaetano, A.T., Kuniholm, P.I., Newton, M.W., 2007. A regional high-frequency reconstruction of May-June precipitation in the north Aegean from oak tree rings, A.D. 1089-1989. Int. J. Climatol. 27 (8), 1075–1089. DOI10:1002/joc.1459.

Haneca, K., Čufar, K., Beeckman, H., 2009. Oaks, tree-rings and wooden cultural heritage: a review of the main characteristics and applications of oak dendrochronology in Europe. J. Archaeol. Sci. 1 (36), 1–11. https://doi.org/10.1016/j.jas.2008.07.005.

Hollstein, E., 1980. Mitteleuropäische Eichenchronologie: Trierer dendrochronologische Forschungen zur Archäologie und Kunstgeschichte (Trierer Grabungen und Forschungen). Zabern Verlag, Mainz, Germany, p. 273.

Klippel, L., Krusic, P., Brandes, R., Hartl-Meier, C., Trouet, V., Meko, M., Esper, J., 2017. High-elevation inter-site differences in Mount Smolikas tree-ring width data. Dendrochronologia 44, 164–173.

Kuniholm, P.I., 1996. Long Tree-Ring Chronologies for the Eastern Mediterranean. In: Demirci, S., Czer, A.M., Summers, G.D. (Eds.), Archaeometry 94: The Proceedings of the 29th International Symposium on Archaeometry. TUBITAK, Ankara, pp. 401–409.

Kuniholm, P.I., Striker, C.L., 1983. Dendrochronological investigations in the Aegean and neighboring regions, 1977–1982. J. Field Archaeol. 10, 411–420.

Kuniholm, P.I., Striker, C.L., 1987. Dendrochronological investigations in the Aegean and neighboring regions, 1983–1986. J. Field Archaeol. 14 (4), 385–398.

Macchioni, N., Brunetti, M., Pizzo, B., Burato, P., Nocetti, M., Palanti, S., 2012. The timber structures in the Church of the nativity in bethlehem: typologies and diagnosis. J. Cult. Herit. 13, e42–e53. https://doi.org/10.1016/j.culher.2012.10.004.

Makris, P., Christopoulou, A., Konidi, A.-M., Gmińska-Nowak, B., Tsakanika, E., Ważny, T., 2021. Interpreting the story old timber can tell: an example from a 'Venetian' building in nafplio. Int. J. Archit. Herit. https://doi.org/10.1080/15583058.2021.1963505.

Miles, M., 1997. The interpretation, presentation, and use of tree-ring dates. Vernac. Archit. 28 (1), 40–42. https://doi.org/10.1179/030554797778605056.

Rinn, F., 2011. TSAP-Time Series Analysis and Presentation for Dendrochronology and Related Applications; Version 4.64 for Mi-crosoft Windows—User Reference. Rinntech Inc, Heidelberg, Germany.

Schweingruber, F.H., 1988. Tree Rings: Basics and Application of Dendrochronology. D. Reidel Publishing, Dordrecht, Holland.

Seim, A., Buentgen, U., Fonti, P., Haska, H., Herzig, F., Tegel, W., Trouet, V., Treydte, K., 2012. Climate sensitivity of a millennium-long pine chronology from Albania. Clim. Res. 51 (3), 217–228. https://doi.org/10.3354/cr01076.

Tegel, W., Muigg, B., Skiadaresis, G., Vanmoerkerke, J., Seim, A., 2022. Dendroarchaeology in Europe. Front. Ecol. Evol. 10, 823622 https://doi.org/10.3389/fevo.2022.823622.

Tsakanika, E., 2017. Minoan structural systems: earthquake-resistant characteristics: the role of timber. In: Jusseret, Sintubin (Eds.), Minoan Earthquakes Breaking the Myth through Interdisciplinarity. Leuven University Press, pp. 267–304.

Tyers, I., 2004. Dendro for Windows Program Guide, 3rd ed.; ARCUS Rep 340. University of Sheffield, Sheffield.

Ważny, T., Kuniholm, P., Pearson, C., 2020a. Dendrochronological dating of the Bailo house with a supplementary comment on the church of Agia Paraskevi. Chapter 3D. In: Kontogiannis, N.D., Skartsis, S.S. (Eds.), Venetian and Ottoman heritage in the Aegean: The Bailo house in Chalcis, Greece. Brepols Publishers, Belgium, pp. 169–182.

Ważny T., Tzigounaki A., Rackham O., Moody J., Helman-Ważny A., Pearson C., Giapitsoglou K., Troulinos M., Fraidhaki A., Apostolaki N., 2020b. Trees, Timber and Tree-rings in Historic Crete, Byzantine to Ottoman. In: Αρχαιολογικό Έργο στην Κρήτη 4, 339-349.

Wheeler, E.A., 2011. Insidewood – a web resource for hardwood identification. IAWA J. 32 (2), 199–211.