Article

Analysis of the Natural Aging of Silver Fir (Abies alba Mill.) Structural Timber Using Dendrochronological, Colorimetric, Microscopic and FTIR Techniques

Matjaž Dremelj, Klemen Novak, Maks Merela and Aleš Straže*

Biotechnical Faculty, University of Ljubljana, Jamnikarjeva 101, 1000 Ljubljana, Slovenia; matjaz.dremel@gmail.com (M.D.); klemen.novak@bf.uni-lj.si (K.N.); maks.merela@bf.uni-lj.si (M.M.)

* Correspondence: ales.straze@bf.uni-lj.si; Tel.: +386-1-320-3635

Abstract: Timber, as a building material, is subject to structural changes in the used interior, which result from the influence of various local environmental conditions and their changes during the service life. Samples of naturally aged historic silver fir (Abies alba Mill.) wood were taken from the roof of St. Barbara Church (Ravnik above Hotedrišca, Slovenia). The slices of historic wood were dendrochronologically dated and analyzed by CIELab color determination, light microscopic analysis and IR spectroscopy. Our results showed that the interior of the 18th-century fir structural timber had lower color lightness (L*) and intensity (b*), particularly in the latewood. The partial increase in lignin and decrease in hemicelluloses relative to cellulose content, associated with an increased degree of crystallinity of cellulose, was confirmed by epifluorescence and polarized light microscopy combined with FTIR spectroscopy.

Keywords: wood; structural timber; aging; dendrochronology; color; microscopy; FTIR spectroscopy

1. Introduction

As a natural polymer composite material, wood is subject to photodegradation, biodegradation, structural changes on the surface and inside, and aging during its service life. Under certain conditions of wood use, especially when wood is used indoors, the first two factors (photodegradation and biodegradation) can have negligible effects, while the natural aging process becomes the predominant factor leading to changes in the material [1]. Even in structural timber, if we talk only about the internal load-bearing core, some researchers have found slight chemical changes, existing internal stresses and altered hygroscopicity and viscoelasticity of the material after prolonged use [2]. Due to the hygroscopic nature and changing moisture content of the material, as well as the viscoelasticity of the wood, internal stresses also occur during the service life [1].

Natural aging of wood is relatively less studied in different geographical areas and is usually interpreted as a slow process of mild thermal oxidation in the range of natural temperature variations, where oxygen is dissolved in air or water, and hydrolysis due to the content of acids and bound water in wood [3]. Under humid conditions, some organic acids such as 4-methylglucuronic and galacturonic acid can be formed in very low concentrations in wood [1,4]. Natural aging of wood most frequently shows changes in hemicelluloses, which are the least stable components [5–7]. FTIR spectroscopy and chemical analytical studies confirm a decrease in the proportion of free hydroxyl groups, which in turn leads to a decrease in hygroscopicity and thus greater dimensional stability of aged wood [8,9]. Natural aging of wood may also be accompanied by an increase in the degree of crystallinity of cellulose [10], as evidenced by the formation of new intermolecular bonds in amorphous regions.

The color change during the natural aging of wood is mainly attributed to slow and mild thermal oxidation [3]. However, the color change of wood may also be due to changes...
in the proportion of extractives and their chemical structure [5], which increases in aged wood due to degradation of the structure, and oxidation of lignin and hemicelluloses [6,11]. Studies have consistently reported darkening of color in wood after prolonged use [3,12], with greater color differences observed in some softwoods [6]. However, the change in wood color depends not only on environmental conditions but also on wood species and differences in their chemical composition [3].

Several studies have also reported changes in the microstructure of naturally aged wood, such as an increase in porosity, delamination and the appearance of radial and helical cracks in the fiber cell walls [1,2,13]. Without knowing the exact history of the wood, it is difficult to determine whether structural defects are solely due to natural aging. Other factors, such as sample preparation and the magnitude and dynamics of internal stresses, may also contribute to the observed defects. Structural defects are more likely to occur in areas where hemicelluloses, pectin and lignin are present in greater amounts [14].

The aim of this study was to verify some chemical and anatomical changes in wood due to aging, resulting from the fact that a wooden structure with a roof protected from weathering is exposed to certain local environmental conditions and their changes during its service life. In particular, the applicability of microscopic and chemometric methods for monitoring the aging process of structural wood was verified.

2. Materials and Methods

2.1. Sampling

Samples (n = 32) of naturally aged historic silver fir (Abies alba Mill.) wood were obtained from the roof of the church of St. Barbara, in the village of Ravnik above Hotedršica (N 45.92083°, E 14.15692°, 637 m a.s.l.), in Slovenia (Figure 1). The study included rafters, beams, joists and posts with a cross-section of structural elements from 16 × 16 cm to 25 × 25 cm. In parallel, we sampled wood from silver fir trees felled in 2019 at several sites in nearby fir-beech (Abieti-Fagetum) forest stands and in the alpine and subalpine region of Gorenjska in Slovenia. These samples were used for comparison with the historic wood. For the analysis, 5 cm thick slices from elements of the wood structure of the church (n = 10) and from the breast height (1.3 m above the ground) of the felled trees (n = 10) were used.

Figure 1. Geographical location of the sampling of the recent wood and the research object St. Barbara Church on the map (a) and part of the old wooden roof structure of the church (historic wood) with marked places of sampling (colored red) (b).

2.2. Sample Preparation and Dendrochronological Analysis

The discs of the historic wood were sanded with a belt sander with grit sizes 80, 120, 180, 240, 280, 320 and 400. Subsequently, the discs were scanned with a resolution of 1200 dpi (Mustek S 2400 Plus). The CooRecorder 9.5 software was used to measure the tree ring widths (TRW) and the widths of the earlywood (EW) and latewood (LW), and dendrochronological dating was performed by using the TSAPWin software (Figure 2) and the Slovenian silver fir reference chronology [15,16]. In this way, the end date was
determined for each wooden element, and the year of tree felling was estimated [17]. The year of felling was then used as the beginning of wood aging.

Figure 2. Scanned disc from the structural element of the church roof (a), principle of dendrochronological measurement with the positioning of the tree ring boundaries (b) and sampling of the cube-shaped blocks (1 × 1 × 1 cm³) for microscopy and FTIR analysis (c) (J—juvenile wood (first 20 growth rings), JA—transition between the juvenile to adult (mature) wood (20th to 40th growth ring) and A—adult wood (close to the circumference, >40th tree ring).

2.3. Determination of Wood Color

The color profiles of the scanned slices were acquired using CooRecorder 9.5 software according to the method of the BI (blue intensity) measurement system [18]. The color parameters (R-red, G-green, B-blue) were determined separately for early- and latewood in each tree ring. The conversion of the RGB values to a standard CIEL*a*b* color system was then performed using the Color Conversion Center 4.0a algorithm in MS Excel (http://ccc.orgfree.com/, accessed on 10 October 2022).

To verify the color values of the samples obtained with the scanner (Mustek S 2400 Plus) and CooRecorder 9.5 software, we also used the standard CIEL*a*b* method with the SP62 X-Rite spectrophotometer (X-Rite, Regensdorf, Switzerland.). We acquired standard CIEL*a*b* color values from the pith to the circumference of each examined disc, including J-, JA- and A- locations (Figure 2), with a positional shift of 2 cm, equal to the aperture size of the spectrophotometer. In parallel, we determined the average color value on 2 cm sections obtained by RGB measurements with the scanner (and by conversion in CIEL*a*b*) on the early- and lateward of each growth ring. To compare the individual color values of the scanned samples and the standard CIEL*a*b* method, we performed descriptive statistics of the means (F-test and l-test) and tested the correlation. In individual comparisons, e.g., for recently felled and historic samples of RAD03-03B and BAR25B (Figure 3), we confirmed significant differences for the mean values of the color parameters \( L^* (L^*_\text{ref} = 68.50; L^*_\text{scan} = 64.92; p = 0.03) \) and \( a^* (a^*_\text{ref} = 7.73; a^*_\text{scan} = 9.85; p < 0.01) \), but not for \( b^* (b^*_\text{ref} = 18.51; a^*_\text{scan} = 19.03; p = 0.31) \) and total color \( E^* (E^*_\text{ref} = 71.30; E^*_\text{scan} = 68.42; p = 0.13) \). Reliable linear regression was confirmed when comparing the two methods for parameters \( E^* (R^2 = 0.96) \) and \( L^* (R^2 = 0.95) \) and slightly weaker for parameters \( a^* (R^2 = 0.71) \) and \( b^* (R^2 = 0.37) \). The measured total color difference (\( \Delta E^* \)) between the used methods was 4.20 (CV (%)—coefficient of variation, CV = 18.4%) and less than the ability of human perception (\( \Delta E^* \geq 6.0 \)) [19] for all samples tested.
2.4. Light Microscopy Analysis

Samples for the light microscopy were prepared at three locations on discs, from the pith to the circumference (J—juvenile, JA—juvenile-adult and A—adult; Figure 2). Thin sections (20 µm) were cut from the blocks (1 × 1 × 1 cm³) in 3 anatomical planes (transverse, radial and tangential) on the sliding microtome (Leica SM 2000R) after 7 days of softening in a solution of water and ethanol. The sections for the bright field light microscopy analysis were stained with a mixture of astra blue and safranin [20,21]. The sections for epi-fluorescence and polarization techniques were stained with a solution of acridine/chrysoidine (0.5 g acridine red + 0.5 g chrysoidine in 190 mL distilled water) [22]. Three sections (transverse, radial and tangential) were mounted in Euparal resin (3C-239; Chroma).

Anatomical examinations of the samples were performed on a Nikon Eclipse E 800 light microscope using bright-field, polarization and epi-fluorescence modes. Changes in cellulose crystallinity were examined using the polarization technique, and changes in lignin were observed by using epi-fluorescence. For the latter, a combination of filters (EX 330–380) and a dichroic mirror (BA 420) was used. A Nikon DS-01 digital camera was used for microphotography, and images were processed and analyzed using the computer program NIS Elements BR 3.0.

2.5. Analysis of Chemical Changes Using FTIR Spectroscopy

FTIR analysis was performed like the microscopy on the cubical blocks taken from three locations in the direction from the pith to the circumference of the studied discs (Figure 2). Longitudinally oriented thin sections (LR-plane) of 20 µm thickness were made from individual blocks in the dry state using a Leica SM 2000R sliding microtome. The sections were then placed in a transmission sample holder of the Spectrum TWO IR spectrophotometer. The absorption IR spectrum of each sample was recorded in the wavenumber range 400–4000 cm⁻¹, with a resolution of 1 cm⁻¹, and 16 scans were made. Even though the thin sections were produced using a microtome, they still might vary in thickness. Therefore, three different 100 × 100 µm areas of each section were measured by repositioning the thin section to get good coverage of the whole sample. The acquired spectra were saved in the raw.csv format for further processing.

Spectral Data Analysis

Spectral data obtained from the samples were baseline corrected in Spectrum 10 software. We used poly-baseline correction with seven flattening frequencies: f₁ = 3764 cm⁻¹, f₂ = 3003 cm⁻¹, f₃ = 2635 cm⁻¹, f₄ = 1810 cm⁻¹, f₅ = 1538 cm⁻¹, f₆ = 1186 cm⁻¹, f₇ = 918 cm⁻¹. It is possible to correct the baselines of the spectra so that linear baselines are drawn between the same frequencies for each spectrum, resulting in a more reproducible peak analysis of the spectra [8,23–25]. The absorbance at flattening frequencies was subtracted from the uncorrected spectra to produce baseline-corrected spectra (Figure 4).
The hemicelluloses in softwoods are represented by glucomannans and glucuronoxylans, with peaks at 1509 cm$^{-1}$ to be the limit of the peak at 1509 cm$^{-1}$ for the lignin peak between 1504 cm$^{-1}$ and 1513 cm$^{-1}$ [8]. This peak is assumed to be specific to lignin as it corresponds to a stretching vibration mode on the benzene ring, which occurs mainly in the lignin polymer [23,26,27]. The averaged absorbance values of the fingerprint and the peak at 1509 cm$^{-1}$ were then evaluated in a similar manner (Equation (1), Figure 4) [8].

$$\text{Lignin ratio} = \frac{\text{Lignin average}}{\text{Inner fingerprint average}}$$  \hspace{1cm} (1)

To determine the ratio for the hemicelluloses, the average was calculated for the acetyl C = O stretching peak of the hemicelluloses between 1724 cm$^{-1}$ and 1728 cm$^{-1}$. Indeed, the peak at 1726 cm$^{-1}$ refers to the acetyl groups found on the hemicellulose polymers. The hemicelluloses in softwoods are represented by glucomannans and glucuronoxylans, only the former being acetylated [28,29]. The ratio was then calculated (Equation (2), Figure 4) [8]:

$$\text{Acetyl ratio} = \frac{\text{Acetyl average}}{\text{Inner fingerprint average}}$$  \hspace{1cm} (2)

3. Results

For St. Barbara Church, 7 out of 10 structural silver fir wood samples were dated and the felling dates of trees were determined to be 1772 and 1858, indicating that the roof of the building was presumably restored during its use, as usually observed on historic objects. The last reconstruction, with elements not used in this study, was carried out in 2019.
3.1. Growth Characteristics of Wood Samples

Tree ring patterns of recently felled silver fir wood from uneven-aged mixed forest stands showed a decreasing growth trend from the juvenile to the adult period, progressing from the pith to the bark of the trees. (Figure 5a,b; Figure 6). The average tree ring width (TRW) in the juvenile wood (first 20 annual rings from the pith) was 2.54 mm (CV = 45.5%) and in the adult part (>40th annual ring from the pith) was 1.61 mm (CV = 71.3%). In parallel, the proportion of latewood increased slowly with distance from the pith, from an average of 25.7% (CV = 22.9%) in the juvenile wood to 29.3% (CV = 30.8%) in the adult wood of the samples.

Figure 5. Tree-ring width and latewood proportion related to cambial age (years from the pith) in recently felled silver fir (a,b) and in historic silver fir structural wood from trees felled in 1772 (c,d).

Figure 6. Visual appearance of recent silver fir wood from trees felled in 2019 (a–d) and historic silver fir wood from the roof of St. Barbara Church with a felling date of 1772 (e–h); samples have different cambial ages and number of annual rings.
The tree ring pattern of the historic wood was uniform in the central part of the stems while the TRW abruptly increased toward the periphery (Figure 5c,d; Figure 6), possibly due to the felling of nearby trees, while other factors influencing wood formation are generally unknown for historic wood [30–32]. The juvenile wood of historic structural elements had on average narrower tree rings (TRW = 1.47 mm; CV = 49.8%) with a lower proportion of latewood (LWP = 32.7%; CV = 16.4%) than the adult wood (TRW = 2.49 mm, CV = 43.5%; LWP = 37.6, CV = 14.2%).

3.2. Visual Appearance of Wood Samples

We visually confirmed the characteristic color differences between recent and historic silver fir wood. All recent wood samples (Figure 6a–d) were generally brighter across the entire cross-section than historical wood (Figure 6e–h). Specimens from both groups were locally found to have darker coloration, especially near the pith in tree rings with a gradual transition from early to latewood and in those with a high proportion of latewood, which is typical of compression wood that often forms in silver fir and other conifers in response to altered gravitropism due to growth disturbances [33,34].

3.3. Analysis of Wood Color

The color lightness ($L^*$) of early- and latewood of the recent wood samples was constant, independent of the distance from the pith. As expected, 15 to 20 units higher values were obtained in earlywood (Figure 7a,c). In the historical structural wood of silver fir, we found comparable color lightness of early- and latewood, with the values of the recent wood appearing only in the outer part of the cross-section of structural elements. As we approached the pith, we noted a trend toward a significant decrease in color lightness in both early- and latewood. The historic structural timber exhibited the greatest decrease in lightness near the pith. This was especially true for the latewood, where the difference could be as much as 30 units, and as much as 15 units for the earlywood ($t$-test; $p < 0.01$).

The parameters $a^*$ and $b^*$, describing chromatic coordinates on the green-red ($a^*$) and blue-yellow ($b^*$) axes, were both relatively constant and showed some local variability, in the radial direction of the samples in both groups studied. Both parameters reached the highest values in the latewood of recent silver fir. In contrast, the lowest values were measured in the earlywood of historic fir timber. Similar to the color lightness $L^*$, it can be observed that the parameters $a^*$ and $b^*$ decreased the most in the latewood due to aging.

The total color $E^*$, determined by the parameters $L^*$, $a^*$ and $b^*$ as the geometric distance from the center of the color space, was relatively stable in recent silver fir, regardless of position or distance from the pith. This observation was consistent for both earlywood and latewood. In historic fir structural wood, $E^*$ reached an equivalent value only at the periphery compared to recent wood samples. Toward the pith of historic timber, the value of $E^*$ typically decreases (Figure 7).

The average color characteristics of the test samples measured with the CIEL*a*b* spectrometer at positions J, JA and A (Figure 2) corresponded to the color profiles determined with the scanner (Figure 8). For recent wood, stable values were found for all tested color parameters ($L^*$, $a^*$, $b^*$, $E^*$) at all three tested regions. All parameters, except $a^*$, reached statistically significant greater values ($t$-test; $p < 0.05$) compared to historical fir structural timber. The largest differences, similar to optical scanning color analysis (Figure 7), were confirmed near the pith of the samples, at the location of the juvenile wood (J).
Figure 7. L*, a*, b* and E* color parameters, determined by CooRecorder 9.5 software, of recent fir wood (··· earlywood; — latewood) and structural timber felled in 1772 (··· earlywood; — latewood) (a–d)—comparison of RAD03-03B (recent) and BAR25B (historic); (e–h)—comparison of KRG04-01B (recent) and BAR22B (historic).
Figure 8. The color parameters $L^*$ (a), $a^*$ (b), $b^*$ (c) and $E^*$ (d) of recent (■) and fir structural timber felled in 1772 (■) determined by SP62 X-Rite spectrophotometer at three regions: J—juvenile wood (first 20 growth rings), JA—juvenile-adult wood (20th to 40th growth ring) and A—adult wood (close to the circumference, >40th growth ring).

3.4. Light Microscopy Analysis

When comparing the microscopic images obtained by bright-field microscopy, a lighter red staining was observed in the recently felled wood compared to the naturally aged historic wood (Figure 9: 1st row—JA-R vs. JA-18thC), where a darker red color could be detected. This indicates a relative increase in lignin content with the aging of wood compared to hemicelluloses and cellulose.

Figure 9. Micrographs of recently felled silver fir wood (JA-R, JA-location: 1st column) and structural timber felled in 1772 (18thC) (J-location: 2nd column; JA-location: 3rd column; A-location: 4th column) (1st row: astra blue—safranin staining; 2nd row: polarization technique; 3rd row: epifluorescence). J—juvenile wood (first 20 growth rings), JA—transition between the juvenile to adult (mature) wood (20th to 40th growth ring) and A—adult wood (close to the circumference, >40th growth ring).
Under polarized light, the shining is more intense in historic than in recently felled wood (Figure 9: 2nd row—JA-R vs. JA-18thC). This suggests that the degree of crystallinity of cellulose has increased as the wood has aged, probably at the expense of degradation of the amorphous regions of this basic wood component. In the juvenile wood, which is characterized by a lower cellulose content [5], lower crystallinity [35] and a higher microfibril angle [33] than in the adult wood, a less intense shining was observed.

In the images obtained with epi-fluorescence microscopy, a higher proportion of green-yellow fluorescence is evident in the cell walls and especially in the middle lamellae of the historic wood than in the recently felled wood (Figure 9: 3rd row—JA-R vs. JA-18thC). This is possibly due to a relatively higher lignin content compared to the content of hemicellulose and cellulose in the historic wood, as also shown by viewing the samples with brightfield microscopy.

3.5. FTIR Analysis

The lignin ratio is slightly increased in historic fir structural wood, but we could not statistically confirm differences compared to recently felled wood in the whole samples, but only in their juvenile (J) region. (Figure 10a; t-test, \( p = 0.03 \)).

![Figure 10](image)

**Figure 10.** Lignin ratio (a) and Acetyl (hemicellulose) ratio (b) of recent and 18th century fir structural timber (J—juvenile wood (first 20 growth rings), JA—transition between the juvenile to adult (mature) wood (20th to 40th growth ring) and A—adult wood (close to the circumference, >40th growth ring).

The acetyl ratio decreased in historic fir wood in the adult (A) wood zone, indicating slight degradation of hemicelluloses (Figure 10b; t-test, \( p = 0.02 \)). No differences in acetyl ratio were found inside the fir samples studied (J- and JA-region; t-test, \( p = 0.17 \)). The changes in the two ratios, i.e., the lignin ratio and the acetyl ratio, do not directly illustrate the absolute changes in the amounts of lignin and hemicelluloses, but only the relative changes in the lignin-carbohydrate complex.

4. Discussion

Historic and recently felled silver fir wood differed in color, which was generally darker in the historic wood, as also shown by other studies on silver fir and other wood species [1,3]. The color change during the natural aging of wood can be mainly attributed to a slow and mild oxidation process and climatic variations [3]. The greatest differences were found in the parameter \( L^* \), which indicates the lightness of the color, which decreases with age. The largest color differences were found in the juvenile wood (J), slightly smaller in the transition from the juvenile to the adult wood (JA) and the smallest in the adult wood (A), which could be due to the different proportions of cell wall components in each zone and the different proportion of extractives. Some studies reported a higher proportion of lignin compared to cellulose in juvenile wood [36]. When comparing recently felled and historic silver fir wood, the color difference seems to be greater in the latewood than in the earlywood. This color difference could be due to the difference in extractives...
content in the latewood compared to the earlywood. In previous studies, the latewood was found to contain less pectin and lipophilic extracts and more galactoglucomannans than the earlywood [36].

On images obtained by various light microscopy techniques, historic wood showed darker red staining by safranin and a higher proportion of green-yellow fluorescence compared to the appearance of recently felled wood, indicating an increase in lignin content relative to the amount of hemicelluloses and cellulose with increasing age of the wood. FTIR analysis also showed an increase in lignin ratio with age, but the differences between historic and recently felled wood could not be statistically confirmed. An increase in lignin content, a decrease in cellulose content, and degradation of amorphous areas have also been reported by other researchers [37,38]. However, by FTIR, a slight degradation of hemicelluloses, determined by acetyl ratio, was also detected in the mature (A-region) historic fir wood, but not in the inner regions of the samples. In recent studies, a slight degradation of hemicelluloses was also detected in aged spruce structural timber [6].

Using polarized light, we detected a glow in the cell walls that were more intense in historic than in the recently felled wood, suggesting an increased degree of cellulose crystallinity with aging. This was also shown in studies of naturally aged oak [10], which explained this phenomenon by the formation of new intermolecular bonds in the amorphous parts. Further chemical studies are needed to confirm the above statements, taking into account the hierarchical wood structure and its variability, including variability at the submicroscopic level. However, conclusions in historical wood research are always limited by the lack of knowledge of the exact exposure conditions during the service life if the wood structure and their effects on the natural aging of the material.

5. Conclusions

1. Wood aging, a slow and mild thermal oxidation process, resulted in a decrease in color lightness ($L^*$) and chroma ($b^*$) in the inner part of structural fir wood from the 18th century. This color change is particularly pronounced in latewood.

2. Microscopic analysis of the studied historic fir wood by staining and epifluorescence confirmed the increase in lignin content in the juvenile-adult region (JA) relative to the content of hemicelluloses and cellulose, which was also confirmed by FTIR spectroscopy.

3. Microscopic analysis of structural fir wood felled in 1772 using polarized light suggests a partly (juvenile-adult (JA) and adult (A) region) increased degree of cellulose crystallinity due to possible degradation of amorphous areas of cellulose and hemicelluloses, which was partially confirmed by FTIR spectroscopy.

Author Contributions: Conceptualization and experiments design, A.S., M.M. and M.D.; M.D. and A.S. performed the experiments; M.D., K.N., M.M. and A.S. analyzed the data; validation and formal analysis, M.D.; writing—original draft preparation, M.D. and A.S.; writing—review and editing, M.D., K.N., M.M. and A.S.; project administration, A.S. and M.M.; funding acquisition, A.S and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Ministry of Education, Science and Sport of the Republic of Slovenia within the framework of the Programs P4-0430 (Forest timber chain and climate change: the transition to a circular bio-economy) and P4-0015 (Wood and lignocellulosic composites), project “Researchers-2.1-UL-BF-952011”, contract no. C3330-19-952011; co-financed by the Ministry of Education, Science, and Sport of the Republic of Slovenia and the EU European Regional Development Fund and by the Slovenian Research Agency (ARRS), and ASFORCLIC Adaption strategies in forestry under global climate change impact, funded under H2020-EU.4.b., grant agreement ID: 952314.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Thanks to Robert Brus of the University of Ljubljana, Biotechnical Faculty to provide access to the historical building and sampling. Special thanks to the technical assistant Luka Krže for the mechanical processing of the samples.
Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References
15. Ćufar, K.; Bizjak, M.; Kuzman, M.K.; Merela, M.; Grabner, M.; Brus, R. Castle Pišče, Slovenia—Building history and wood economy revealed by dendrochronology, dendroprovenancing and historical sources. Dendrochronologia 2014, 32, 357–363. [CrossRef]
18. Rydval, M.; Larsson, L.; McGlynn, L.; Gunnarson, B.E.; Loader, N.J.; Young, G.H.; Wilson, R. Blue intensity for dendroclimatology: Should we have the blues? Experiments from Scotland. Dendrochronologia 2014, 32, 191–204. [CrossRef]
20. Prislan, P.; del Castillo, E.M.; Skoberne, G.; Špenko, N.; Gričar, J. Sample preparation protocol for wood and phloem formation analyses. Dendrochronologia 2022, 73, 125959. [CrossRef]


31. Manetti, M.C.; Cutini, A. Tree-ring growth of silver fir (Abies alba Mill.) in two stands under different silvicultural systems in central Italy. *Dendrochronologia* 2006, 23, 145–150. [CrossRef]


**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.